MECHANICAL ENGINEERING

INCLUDING THE ENGINEERING INDEX

The Rewards of an Engineering Career

...My work, which has been practically continuous, never much considering hours, times, or places, has been a source of the keenest joy; and even though it may not have led to the goal desired it has always led somewhere and added to both experience and caution in pushing forward. In the thrill of the work itself I have always felt that I have had my share of reward. From time to time, often after long periods of research, patient experimentation, and repeated changes, there have come great satisfactions. On such occasions there comes over me a welling up from within, a sort of elation, and life takes on a new and exalted aspect. That is living! These have been my times of reward.

ELMER A. SPERRY

(From response on receiving the John Fritz Medal, presented December 7, 1926. *See page 101.)*

FEBRUARY 1927

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Shock-proof Welding*

OXY-ACETYLENE WELDING is shock-proof. Many engineers have confidence in oxwelded joints, yet few of them realize how rugged they actually are.

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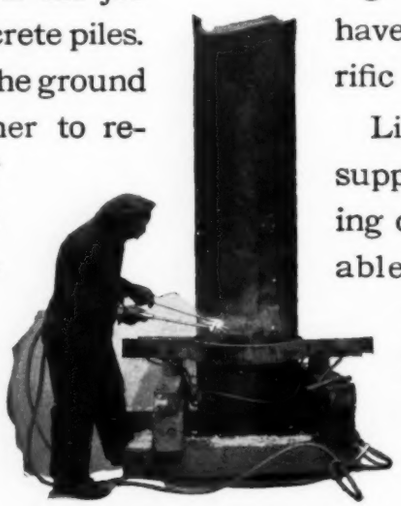

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Mechanical Engineering

The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 20th and Northampton Streets, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-ninth Street, New York

Volume 49 | February, 1927 | Number 2

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Price 60 Cents a Copy, $5.00 a year: to Members and Affiliates, 50 Cents a Copy, $4.00 a year. Postage to Canada, 75 Cents Additional; to Foreign Countries $1.50 Additional. Changes of address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921.

O. W. Boston

W. L. Saunders

B. A. Fiske

Gano Dunn

W. R. Whitney

Contributors to This Issue

Gano Dunn, president of the J. G. Engineering Corporation, New York, holds the degree of B.S. from the College of the City of New York, and an E.E. and honorary M.S. from Columbia. He served as vice-president in charge of engineering and construction with his present concern from 1911 to 1913, and was then appointed president. He is a past-president of the American Institute of Electrical Engineers, the New York Electrical Society, the United Engineering Society and the John Fritz Medal Board of Award. He has been chairman of the National Research Council since 1923. He is a member of the International Electrotechnical Commission; U. S. delegate and vice-president of the International Electric Congress, Turin, 1911; and member of the War Department Nitrate Commission, 1916–18. He is a member of many technical and scientific societies and associations both in this country and in England, and has contributed various papers on electrical and engineering subjects to the technical press.

* * * * *

W. L. Saunders, president and director of the Rand Drill Co., and chairman of the Board of the Ingersoll-Rand Co., was graduated from the University of Pennsylvania in 1876 with the degree of B.S. He is a director of the A. S. Cameron Steam Pump Works, the American International Corporation, the N. Y. & Honduras Rosario Mining Co., and governing director and deputy chairman of the New York Federal Reserve Bank. He is a past-president of the American Institute of Mining and Metallurgical Engineers, the United Engineering Society, and of the American Export Manufacturers' Association. He invented apparatus for subaqueous drilling, using the tube and water-jet system now in general use in the Baku oil fields, Russia; a system of pumping liquids by compressed air; and the radialaxe system of coal mining. He was appointed member of the New Jersey Harbor Commission by President Wilson. He has been a member of the Naval Consulting Board of the U. S. since 1915. He belongs to many other technical and scientific societies as well as educational associations, and is the former editor and now the president of *The Compressed Air Magazine*, and the author of several books and many papers and articles on engineering subjects.

Bradley A. Fiske was graduated from the U. S. Naval Academy in 1874 and served on various duties and stations from then until 1916, when he retired with the rank of rear-admiral. He was cited for "heroic conduct" by Admiral Dewey at the battle of Manila. He served as a member of the First Electrical Conference in Philadelphia in 1884; as a member of the Naval Wireless Telegraph Board in 1904–05; as a member of the General Board of the Navy and also of the Joint Board of the Army and Navy, 1910–11 and 1913–15. He has a large number of inventions to his credit, two of them in use by navies throughout the world—the naval telescope sight and the torpedoplane. In 1893 he was awarded the Elliott Cresson Medal by The Franklin Institute, and in 1919 a gold medal by the Aero Club of America for his invention of the torpedoplane. He was president of the U. S. Naval Institute from 1911 to 1923 and is honorary president of the Army and Navy Club of New York. He is the author of several books as well as numerous articles on electrical and naval subjects.

* * * * *

S. W. Miller is consulting engineer with the Union Carbide and Carbon Laboratories, Long Island City, N. Y. He is a graduate of Stevens Institute of Technology, and during his career has been connected with the Pennsylvania Lines, the American Locomotive Co., and the Rochester Welding Works, of which latter he is proprietor.

* * * * *

O. W. Boston, director of the engineering shops, University of Michigan, was graduated from the engineering college of that institution in 1913, later taking master's and mechanical engineering degrees. He served for four years as an instructor in engineering mechanics, resigning at the start of the war to accept a commission in the U. S. Navy, where he was assigned to duty in the Bureau of Ordnance on design and manufacture of submarine mines used in the North Sea barrage. From 1919 to 1921 he was engaged in industrial-engineering work for the Cleveland Tractor Co., as assistant to the vice-president and works manager, returning to the University of Michigan in 1921.

S. W. Miller

T. W. Greene

* * * * *

T. W. Greene, Engineer, Engineering Development Section, Linde Air Products Company, was graduated from Indiana University in 1917. During the war, he served as a flying officer in Aviation Corps. For five years prior to his employment in the Linde Air Products Company, he was assistant engineer-physicist in Engineering Mechanics Department, U. S. Bureau of Standards. He is the author of several Bureau publications and technical articles.

* * * * *

W. R. Whitney, director of the Research Laboratory of the General Electric Co., Schenectady, N. Y., since 1904, was graduated in 1890 from Massachusetts Institute of Technology with the degree of B.S. He received his Ph.D. from the University of Leipzig in 1896. He taught at M.I.T. until 1904 as assistant professor and professor of chemistry, and was then for four years non-resident associate professor; since then he has been non-resident professor of theoretical chemistry. He is a member of the Corporation of M.I.T., a member of the U. S. Naval Consulting Board since 1915, and a member of the advisory committee of the U. S. Bureau of Standards (1925–1930) and of the National Research Council. He is a past-president of the American Chemical Society and a member of many scientific associations. He was awarded the Willard Gibbs Medal from the American Chemical Society in 1916; the Chandler Medal from Columbia University in 1920, and the Perkin Medal from the American Section of the Society of Chemical Industry in 1921.

MECHANICAL ENGINEERING

Volume 49 February, 1927 No. 2

The Engineering and Scientific Achievements of Elmer Ambrose Sperry

One of the outstanding ceremonies of the 1926 Annual Meeting of The American Society of Mechanical Engineers was the presentation on Presidents' Night of the John Fritz Medal to Dr. Elmer Ambrose Sperry. The award was nade by the John Fritz Medal Board, which is representative of the Four Founder Societies, in recognition of Dr. Sperry's development of the gyro compass and application of the gyroscope to the stabilization of ships and airplanes. Addresses upon this occasion by Gano Dunn, W. L. Saunders, and Rear Admiral Bradley A. Fiske immediately follow.

I—Sperry's Early Life and Pioneer Work

By GANO DUNN[1]

FAIR appraisal of a man's achievements is aided by knowing somewhat intimately his parentage and early surroundings. Elmer A. Sperry's father was the oldest son of an oldest son of the Sperry line, extending back to Richard, who came to this country in 1634. From Norman stock, the father inherited the trait of industry, with a leaning toward machinery. He was a hard-working man, always in one way or other connected with lumber, its production, transportation, or sale. He was a great reader. Elmer's mother was a woman of culture, educated at Rutgers, in those days near Hanover Square in the city of New York. She was studious, being especially fond of mathematics, and led her classes in a number of subjects—in trigonometry before she was 16. She left her son when she died at the age of 21, soon after his birth, several works and a great chart on astronomy, algebras, geometries, and many other books, with treasured little quotations on the flyleaves. So the boy missed what should have been his most precious heritage, training by such a mother; but his remarkable Puritan paternal grandparents did their best to make up this great loss.

Sperry was born and reared in Cortland, the geographical center of the state of New York, the county seat, containing the court house with all appurtenances, the county clerk's office, the fair grounds, focusing all of the happenings in the entire county. The town, then of 5000 inhabitants, is in the uplands, among hills heavily wooded with rock maple and beech, which glow with a marvelous splendor in the autumn. Through the valley runs a beautiful river which furnished water power for mills along its banks. Whether sawmill or "grist mill," our medalist at an early age knew their every mechanical detail and ran many a risk in his investigations among the rapidly revolving cogs.

Early Schooling

There was also a scholastic interest to this township. It contained one of New York State's first normal schools, a noteworthy institution, attracted by a former, noted seat of learning, the Cortland Academy, connected more or less intimately, it is believed, with the early life of Ambassador Andrew D. White, for many years president of Cornell, and other prominent citizens of the region. This school brought to the town a wonderful group of trained teachers, who easily became leaders in the community life, as they entered freely into the meager assortment of sports, the many activities of the churches, the Young Men's Christian Association, and lecture courses. This Normal and Training School naturally became the social center. All its functions were of high order and won the confidence of the whole population.

One of Sperry's earliest recollections is the pall of gloom that suddenly overspread the countryside when Lincoln was assassinated. Another is that his father came home from construction of a steam sawmill and took him to see the work many miles away. The boy's heart was fired when his father climbed up on the big flywheel of the engine and caused it to turn. It seemed the most gigantic wheel in the world; his father had actually caused it to move, and he could think of nothing else for days. Most exciting of all was the great instrument case connected with the physics department of the Normal School, visited and pondered over with regularity. Although in the primary department, he was known to the professor in physics and his assistant. Through his intense interest and understanding of the function and fine points of construction of each piece, he was allowed closer inspection and finally access to the operation of much of the apparatus. He could be fully trusted even to mend any part that had become crippled.

Young Sperry went through the three departments, commencing with the lowest classes in the primary, and an excellent training it proved. The high order of mathematical instruction was noteworthy, under a talented and enthusiastic teacher. To Sperry's fresh mind, geometry disclosed a new world. It was an open book, almost too apparent and easy. The high character of the teaching is shown by the fact that the students were required to start with a few postulates and work out an original solution of each problem presented, bringing it on paper the next day. Before the class had reached the well-known Pythagorean proposition, Sperry had found not one but a number of original solutions; his enthusiasm rose to such a pitch that he was found one evening by the professor under a lamp post, working out solutions. He succeeded in finding no less than sixteen original ones. Professor Capen presented him with a large blank book and urged him to enter all these and keep them, which he did with much care.

Following the Puritanical example of his grandparents, the boy took life seriously, feeling it his duty to attend jail meeting with two or three other devoted souls early Sunday morning; then the church service; then, after he was seventeen, in Sunday school he had what he describes as a perfectly wonderful class of younger boys; then the interesting "Y" meeting Sunday afternoon, always led by some of the Normal School professors, followed by the regular evening service, thus making his Sundays nothing short of Puritan in fact.

Visit to the Centennial Exposition

He utilized his time after school in a book bindery, where he earned money which he saved, so that when he was sixteen years old he had enough to take his first journey, joining his companions in a "Y" excursion to spend a week at the Centennial Exposition in Philadelphia. He and his chum were put up at a private residence, which accommodated many more than it really should, so a little cot was put in the "parlor" and alternately one slept on the sofa and one on the cot. Innocently they were proud of being "parlor boarders," and put up with a lot of inconveniences of which they were totally unaware.

The Machinery Building was young Sperry's Mecca. Daily he worshipped among the riot of machinery, much of which was in actual operation. His mechanical knowledge was increased. He would study for hours over a Jacquard loom, and would not leave

[1] Past-President, American Institute of Electrical Engineers; Chairman National Research Council, Washington.

until he understood every movement of the intricate mechanism. It probably was lucky for him that the Mergenthaler linotype had not yet been conceived. The great Corliss engine with its huge walking beams and stupendous flywheel was in the center of Machinery Hall. He often stood close to the engineer when it was started and on one occasion was allowed to take hold of the starting wheel through the indulgence of the benign general superintendent, whose acquaintance he had made. This engine and the Gramme electrical generator in which he was intensely interested and which he recognized as an old friend brought down from Cornell, are his outstanding memories. He was too young to have had the exhibit showing the beginnings of the Bell telephone brought to his attention, that being of interest only to grown-ups.

The Centennial visit was his first experience in a big city. The landlady, who had a bright daughter, suggested that the two "parlor boarders" should see the marvelous performance of Jules Verne's play Around the World in 80 Days, to which the daughter and a girl friend would act as guides. The "boarders" could hardly wait for the evening to come, when, togged out in their best, they took the two girls. In prominent front seats in the balcony their first theater experience went on marvelously until, quite unexpectedly, an extensive ballet was introduced. Neither reddening youth had ever seen anything of this improper kind before. They felt like crawling under the seats. Looking at each other they glanced uneasily at the girls, whom oblivious to their embarrassment they found innocently wrapped in the scene before them; so they concluded this was probably the way of great cities. Neither of them would for the world have divulged his feelings, but on comparing notes later, both concluded, "Never again."

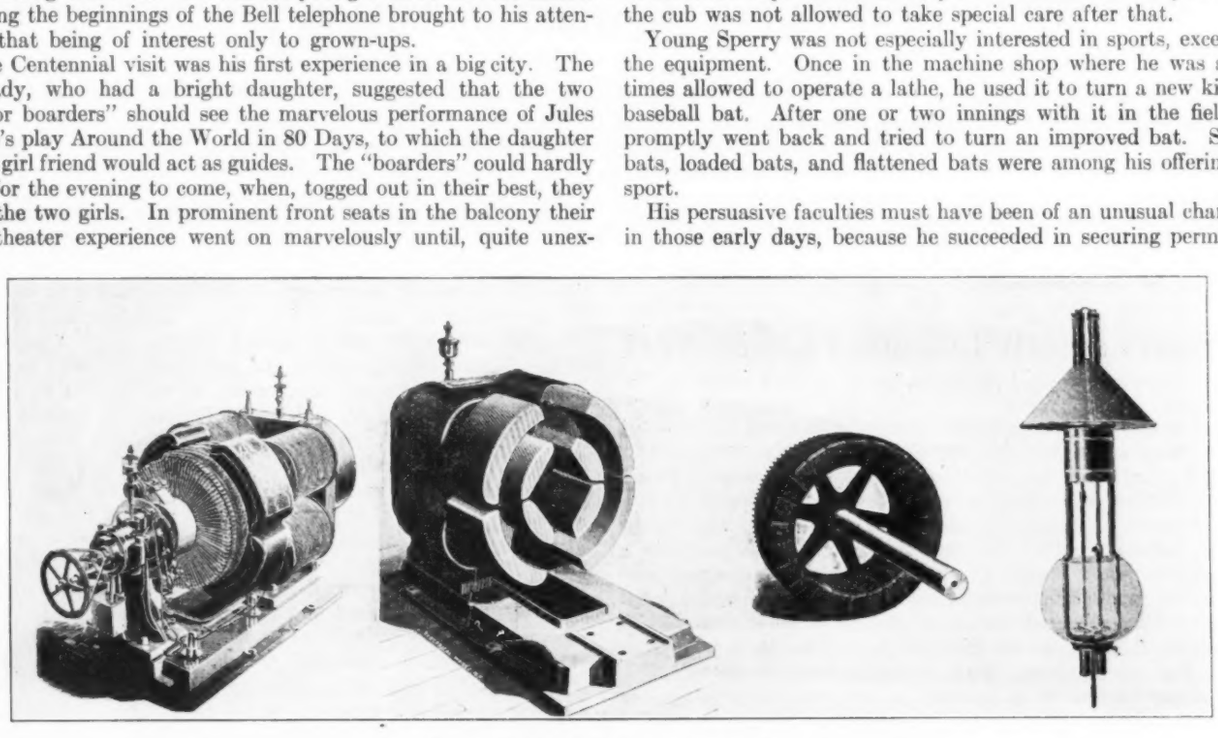

Fig. 1 Sperry's Dynamo and Arc Lamp

Early Interest in Machinery

An advantage of Sperry's home town was its vicinity to the physical and mechanical laboratories of Cornell University, then ruled over masterfully by two great men, the physicist and author William A. Anthony, and the engineer John E. Sweet, in the department of mechanics. Cortland itself possessed a fine machine shop, in which the detail of every machine was well known to the youngster. In the Cortland shop was built the first hydraulic turbine, a little machine with an impeller about one foot in diameter. The boy assisted in its construction in every way possible and was interested in each detail of what became the first installation in the now great hydraulic laboratory at Cornell. He went there and thought he aided in its start. He was so familiar with every machine, not only installed but ordered, that he was usually at the freight depot when it arrived and rode up on the truck which took it to its destination. He would peek through the crate, looking it over and trying to understand all its intricacies even before it was uncrated and set up—whether it were a printing press, or other machine for foundry, wagon shop, or forge.

When very young, at the book bindery Sperry encountered for the first time an intricate automatic paging machine, the apple of the proprietor's eye. After work hours on the second or third day he had this machine all in minute parts on the floor, spread out on a sheet of white paper. The proprietor, surprising him by coming back, turned pale at the sight and was convinced that this fine piece of machinery would never be of use again. Before he knew it, he was helping the boy reassemble it, and in an incredibly short time it was again in operation, the youth insisting that it was much better than ever for having been taken apart and carefully inspected and oiled before reassembling. Only when the proprietor saw it again go merrily on its endless paging excursions did he breathe freely. In the bindery there was no machinery of which the cub was not allowed to take special care after that.

Young Sperry was not especially interested in sports, excepting the equipment. Once in the machine shop where he was sometimes allowed to operate a lathe, he used it to turn a new kind of baseball bat. After one or two innings with it in the field, he promptly went back and tried to turn an improved bat. Spring bats, loaded bats, and flattened bats were among his offerings to sport.

His persuasive faculties must have been of an unusual character in those early days, because he succeeded in securing permission after protracted negotiations in some instances, to put up windmills on the peaks of four or five near-by barns. (He says he certainly must have been a nuisance to his neighbors.) These windmills always did something, the wheel raising a hammer and letting it fall, operating a tiny churn dasher or some kind of a jumping jack. Part of the contract was to keep them running, and he early learned that the simpler ones gave much less trouble. But his delight was to go over to Cornell, and among the physical-laboratory equipment talk with the patient old doctor about all kinds of things on which the boy wanted more information after reading about them in the few scientific journals that reached his town. The Y. M. C. A. furnished the official Patent Gazette each week, and on Tuesday nights he would always squeeze out time enough to run up to its rooms to study the Gazette's marvelous mechanisms, in each one of which he profoundly believed. His trust in some of them far exceeded their merit, but it was all training for his later work.

Building water wheels on the little streams that, especially in the spring, poured down from the hills, was one of his youthful hobbies. He had an intense interest in locomotives, knew all the kinds that passed through the town, and often got rides to the next town by the bribe of fine red apples from his grandfather's farm. He was always trying to build something. He made a glass-blower's outfit and did glass blowing for his boy friends. His experiments with explosive mixtures of benzine vapors injured one of the boys, but this was hushed up and the parents never knew the real cause. The kitchen veranda was set afire on another occasion, but the gang soon had it out and quickly dispersed. He made a railroad tricycle with a very large forward flanged wheel propelled by both hands and feet, with which machine he could keep ahead of the local freight from town to town on the line of the

Delaware, Lackawanna & Western Railroad that passed through his town.

SPERRY'S FIRST DYNAMO AND ARC LAMP

So he grew up in the surroundings described, until at nineteen the urge of construction overcame him and drew him away. Backed by a local industry which had become prosperous, he started to build his first dynamo-electric machine and arc lamp. He had them running successfully in the autumn of 1879. People came for many miles to see electrically made light, entirely new to them at that time. This was within a few days of the date when Edison made his first incandescent lamp from a carbonized thread that had a life of a few hours. He knew a great deal of Edison's activities, but had never seen him nor Menlo Park, which he was destined to visit two or three years later. From Professor Anthony's teaching, the theory of cutting the lines of magnetic force by the armature windings to produce electric current was clear to Sperry at that early time, so he proposed to overhang the Gramme-ring armature and mount it by one end and supply a second internal field. In this way all the internal windings might cut lines of magnetic force as well as the outer layers, which were the only ones utilized in the then current practice. This increased the production of current from a given machine and was a step in advance, as was proved by Professor Anthony's tests. The success and marvelous brilliance of Sperry's new arc light drew capital to the enterprise, and he was sent to a more complete shop in Syracuse to build a large machine running many lights. This machine was no more than completed when he felt the urge to go to Chicago, where he established himself in the business of building these machines and "lighting up the entire Northwest in an effort to put out the stars." (See Fig. 1.)

The first Chicago factory was opened on Sperry's twentieth birthday. In two or three years a great many plants were put in operation, including the highest and most beautiful beacon then in the world, crowning the Board of Trade tower at 350 feet above the Lake level with a corona of 40,000 candlepower of lights. This beacon was maintained by subscriptions of neighbors, the Grand Pacific Hotel, Union League Club, and others, indicating what an asset are the enthusiasms of youth, which are not always appreciated at the time. The Chicago Board of Trade furnished the power and the light was run continuously until the tower, because of insecure foundations, was taken down to save the beautiful building from damage. Later in this article is a reference to his invention in recent years of the brightest arc light known to science.

All this work brought young Sperry into prominence in the West. In 1884, among the organizers or charter members of the American Institute of Electrical Engineers he came from the most remote point. He was the fifth member to enter his name on the original list and take his receipt for the fifteen dollars that each contributed to organize the Institute.

Strange as it may seem, the advance of electric street lighting brought severe competition with the telephone companies, then beginning to have their first little exchanges in the cities. Their universal custom was to use grounded lines. When the lighting plants were started up in the evening, the induction was very serious. Complaints were so numerous and the criticisms so severe that a meeting of the lighting interests in and about Chicago was called at the Grand Pacific Hotel. A committee of three, headed by young Sperry, was requested to draft a pamphlet to be sent to all the electric-light companies throughout the United States, asking them to join in a national conference with a view to unifying the effort at betterment of this and other circumstances, such as franchises and laws, for the good of all. When the time came, the response from Boston to remote parts of the West was universal. The delegates were the most representative men in the United States in this line, and the work done was so useful that then and there was born the National Electric Light Association. It has functioned ever since with great service to this now vastly extended fundamental public utility, and at present has between 17,000 and 18,000 members.

A few years later, Mr. Sperry's interest in electrochemistry led him to become one of the charter members of the American Electrochemical Society.

INDUSTRIAL ELECTRIC LOCOMOTIVES—ELECTRIC STREET CARS

The demand for street lighting and arc lights grew to large proportions and required quantity production of the machines. Commercial production did not interest Sperry, and, being familiar with other forms of generators and the gradual increase in efficiency that was being attained, he made up his mind that should one give a lifetime to the perfection of the generator, only a minute gain would be the ultimate result. He preferred putting electricity to new uses. Transportation had always fascinated him. Opportunity came to design electric locomotives for industrial work, which had to operate on the prevailing yard and entry track which, from the present-day standpoint, was ridiculously light. Think of 5-lb. rails prevailing! Yet a heavy drawbar pull was demanded. Drawbar pull always means weight on the rail, but there was no rail to speak of, so the weight of the locomotive must be divided

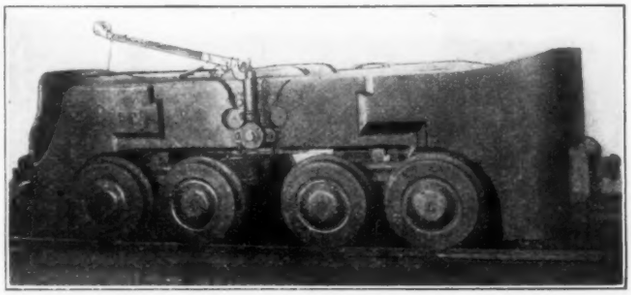

FIG. 2 INDUSTRIAL ELECTRIC LOCOMOTIVE

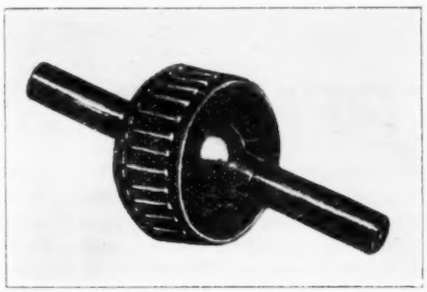

FIG. 3 PIVOT CENTER OF SWIVELING TRUCK OF LOCOMOTIVE

and distributed at many points along the rail. He conceived an eight-wheel locomotive with swiveling trucks, reducing them to extremely simple elements while maintaining their connection with the motor, capable of slipping all the drivers under sand and yet taking a curve as sharp as a 10-ft. radius at speed. Fig. 2 shows a locomotive of this type, made for low-entry work. It was successful and many were made. At the Chicago meeting of the American Institute of Electrical Engineers in 1892, Sperry read a paper giving details quite fully. The swiveling gear constituted at once the truck pivot and the traction transmitter to the locomotive body as shown in Fig. 3.

One purchaser of these industrial locomotives was a large owner in a prominent street railway, where a good deal of hilly country was traversed. He came to Chicago with a proposal that Sperry build him a street car for this line, deriving its traction from all the eight wheels of the two trucks. This was done and a suburban car body and trucks were built by the Pullman Company, the motor and transmission being constructed by Sperry. This car proved so successful that the Sperry Electric Railway Company was immediately organized to build cars of this type, with our present Ambassador to France, Myron T. Herrick, as treasurer. A place was secured at the Brush Electric Works in Cleveland, where construction was started. Hundreds of these cars (see Fig. 4) were built until, in 1894, the whole operation was taken over by the General Electric Company.

ELECTRIC AUTOMOBILES

On the disposal of the electric railway company, Sperry turned his attention to electrically driven automobiles under two heads—

the construction of the vehicle itself, which incorporated many new features, and the development of a light storage battery, which was successful from the first. In the late nineties this vehicle (Fig. 5) was taken to Paris and there showed a performance that was remarkable for the time. It is noteworthy that among the many automobiles Sperry made after returning to the United States, a number were supplied with four-wheel brakes. The Paris electrics were giving about 30 miles per charge, whereas the Sperry with a

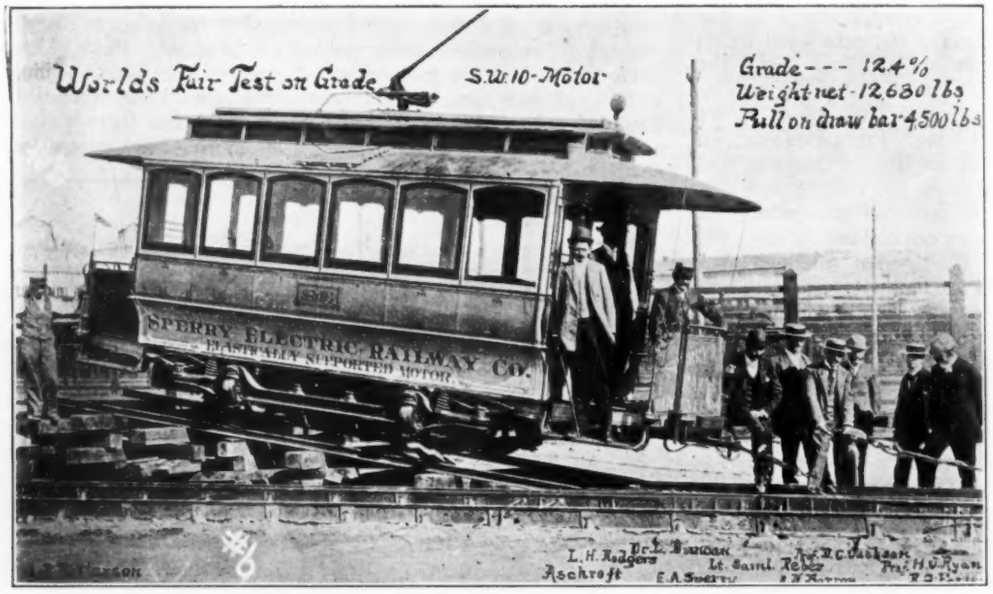

FIG. 4 ONE OF SPERRY'S ELECTRIC STREET CARS ON TEST GRADE AT THE WORLD'S COLUMBIAN EXPOSITION, CHICAGO, 1893. THE HISTORIC GROUP OF ENGINEERS SHOWN INCLUDES THE LATE DR. LOUIS DUNCAN, DR. D. C. JACKSON, AND PROF. H. J. RYAN IN THEIR EARLY YEARS

much lighter battery gave 87 miles. This battery proved to be the forerunner of all the light batteries now used. On his return he made a light battery for the New York Transportation Company, then using a "chloride battery" which was much heavier, giving 36 miles per charge, whereas the Sperry battery gave between 100 and 110 miles regularly. The National Battery Company was formed to manufacture this battery, with works first in Buffalo and later in Niagara Falls, where it continued on a large scale.

SPERRY'S ACHIEVEMENTS IN ELECTROCHEMISTRY

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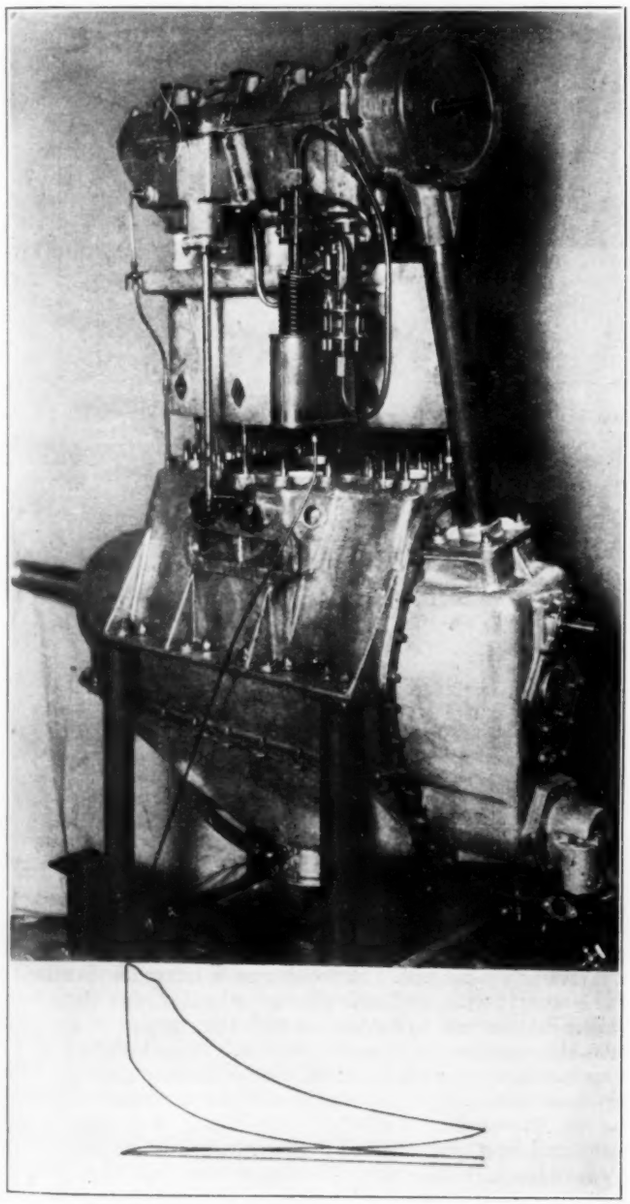

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the construction of the vehicle itself, which incorporated many new features, and the development of a light storage battery, which was successful from the first. In the late nineties this vehicle (Fig. 5) was taken to Paris and there showed a performance that was remarkable for the time. It is noteworthy that among the many automobiles Sperry made after returning to the United States, a number were supplied with four-wheel brakes. The Paris electrics were giving about 30 miles per charge, whereas the Sperry with a much lighter battery gave 87 miles. This battery proved to be the forerunner of all the light batteries now used. On his return he made a light battery for the New York Transportation Company, then using a "chloride battery" which was much heavier, giving 36 miles per charge, whereas the Sperry battery gave between 100 and 110 miles regularly. The National Battery Company was formed to manufacture this battery, with works first in Buffalo and later in Niagara Falls, where it continued on a large scale.

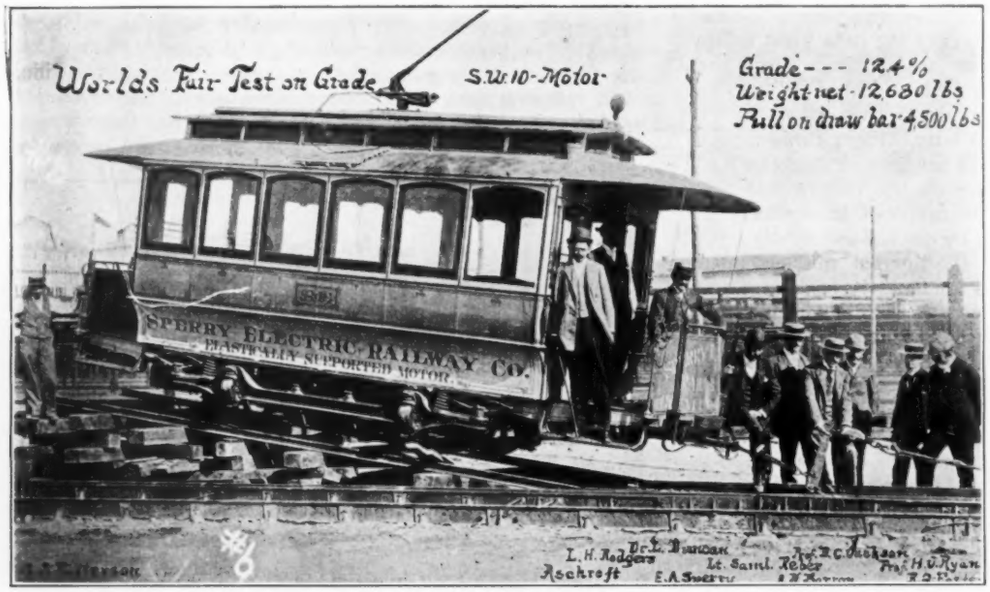

FIG. 4 ONE OF SPERRY'S ELECTRIC STREET CARS ON TEST GRADE AT THE WORLD'S COLUMBIAN EXPOSITION, CHICAGO, 1893. THE HISTORIC GROUP OF ENGINEERS SHOWN INCLUDES THE LATE DR. LOUIS DUNCAN, DR. D. C. JACKSON, AND PROF. H. J. RYAN IN THEIR EARLY YEARS

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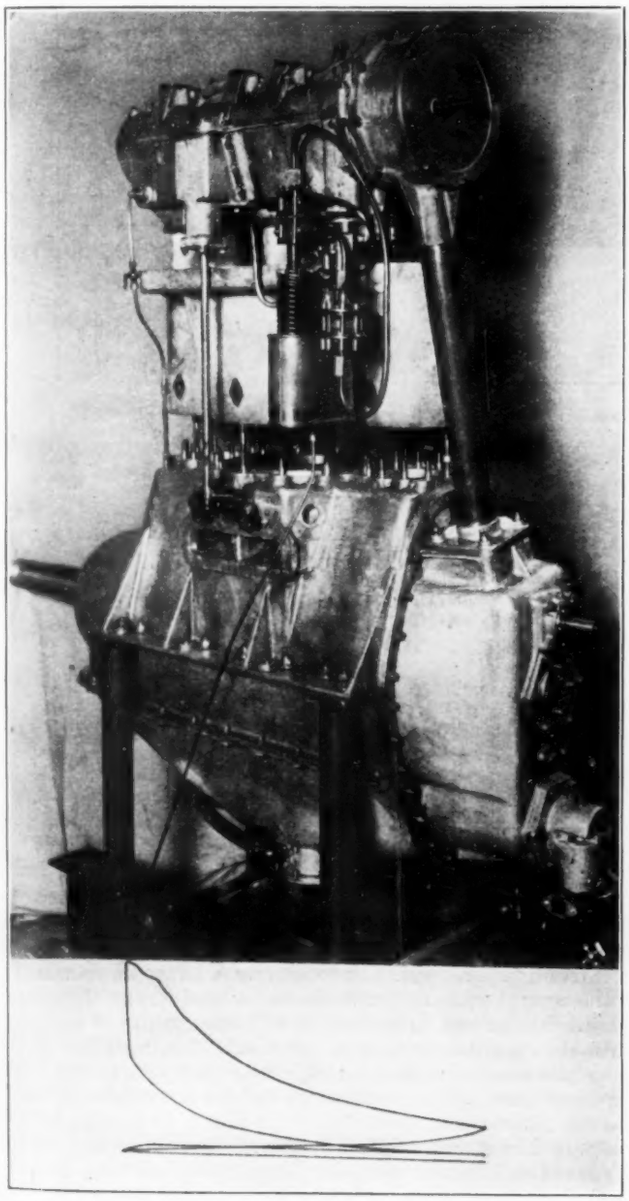

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Coal-Mining Machinery

Mr. Sperry's first electric mining machine (Fig. 7) was designed to reduplicate pick mining, but the power of the stroke was increased about a hundredfold. The machine undercut the coal to a depth of five to six feet, doing the work of many men. A large number of mines were equipped with these machines with excellent success. Machines of this type were afterward replaced by continuously operating chain cutters, which were gradually substituted for the "punchers" until they have become almost universal. The chain

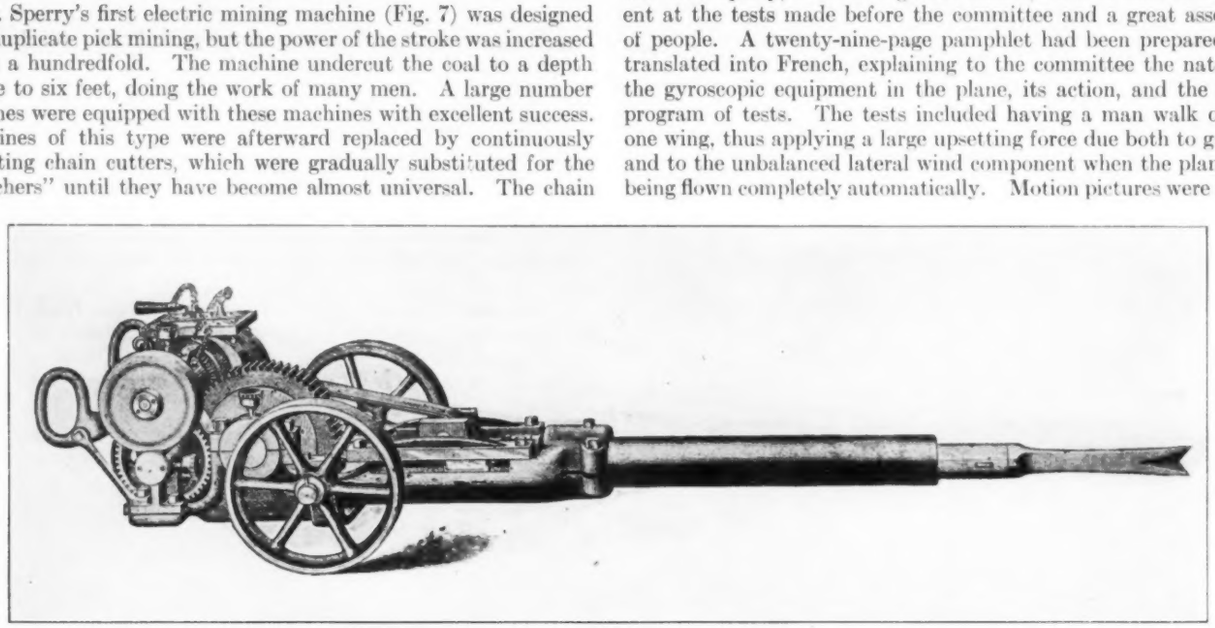


Fig. 7 Earliest Type of Sperry Electric Coal-Mining Machine—the "Puncher"

undercutting machines lend themselves to long-wall, short-wall, room-and-pillar, entry driving, shearing, and other methods of mining. The form of this machine that is most commonly used is shown in Fig. 8.

Wide adoption of these cutting machines led Mr. Sperry to build his own electric generators such, for instance, as shown in Fig. 9, which also served for mine haulage and soon came into demand. The No. 3 mine at Streator, Illinois, was the first one so equipped, on about a 4000-ft. haul, including a grade against the load. A single locomotive could take care of the main-entry haul on a large operation, approximating 1000 tons a day, and save a great outlay in mine mules and their amortization. It was soon found that these mules had to wear rubber nightcaps, because without such protection the least encounter with the 250-volt trolley would usually cause instant death for no physiological reason that was at all apparent; but autopsies showed that the valves of the mule's heart had been turned inside out.

From these small beginnings a large enterprise has grown up, known as the Goodman Manufacturing Company, taking the name from Mr. Sperry's brother-in-law, the late Herbert E. Goodman. The plant is in Chicago and occupies fourteen acres on the South Side. The mining apparatus was exhibited at the World's Columbian Exposition of 1893, together with one of the Sperry arc lamps of very large proportions, used in a projector for throwing a beam many miles across Lake Michigan. The peculiarity of this apparatus was that it also contained some 16-in. lenses, by means of which conjugate foci of an objective could be produced with accuracy at distances up to five miles. With it many startling pictures and announcements of the World's Fair were projected upon the clouds in great size and brilliance throughout the exposition.

Gyroscopic Stabilization of Airplanes

Mr. Sperry moved to New York after living in Cleveland, and upon the organization of the Naval Consulting Board entered actively into its work. For some years prior to this he had been working with his son, Lawrence B. Sperry, on the application of the gyroscope to stabilizing airplanes, aiming at completely automatic flight. The apparatus had reached a state of perfection in 1913 that led to its entry in the Aerial Security contest conducted by the Republic of France, working through the Aero Club of France, in the spring and early summer of 1914. A Curtiss flying boat was equipped with the apparatus in America and shipped to France, where it was reassembled by Lawrence and tuned up in readiness to display to the contest committee of experts, numbering fifteen noted men in aeronautics, science, and Government service. Mr. and Mrs. Sperry, in returning from Russia, were on time to be present at the tests made before the committee and a great assembly of people. A twenty-nine-page pamphlet had been prepared and translated into French, explaining to the committee the nature of the gyroscopic equipment in the plane, its action, and the entire program of tests. The tests included having a man walk out on one wing, thus applying a large upsetting force due both to gravity and to the unbalanced lateral wind component when the plane was being flown completely automatically. Motion pictures were made,

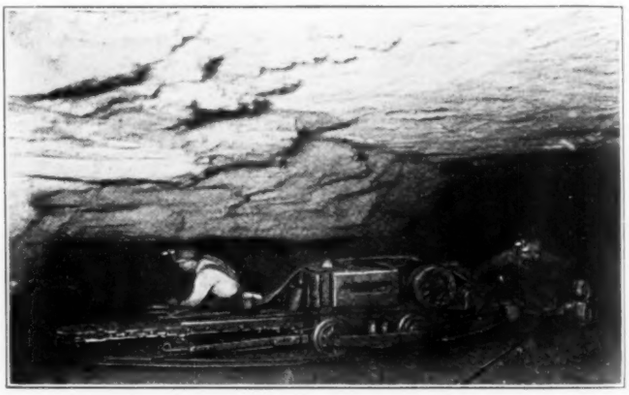


Fig. 8 Later Electric Coal-Mining Machine of the Cutter-Chain Type, One of the Present Standards

showing not the slightest deflection out of the horizontal and no deflection in the line of flight as the man went out, stood there, and later returned to his seat. Mr. Sperry's son Lawrence standing up in the cockpit with his hands above his head during these tests, showed that he had no connection with the controls of the plane while the experiments were in progress. Then members of the committee flew in the plane and had nearby observation of the working of all parts. The committee called for a second test which was run off according to schedule. On July 4, 1914, while in mid-ocean, returning to the United States, Mr. Sperry received a wireless message indicating that the Grand Prize had been awarded him. The French called this device the "automatic pilot." In less than a month Germany had invaded Belgium.

Mr. Sperry was selected by the American Society of Aeronautical Engineers as a member of the Naval Consulting Board. He was placed on the Aeronautical Committee and was afterward made its chairman. He was also chairman of the committees on Mines and Torpedoes, and on Aids to Navigation. He also served on two other committees, namely, Internal-Combustion Engines, and Special Problems.

Work on Submarine-Detection Devices

Mr. Sperry designed a stabilized platform for the magnetic-needle submarine-detector experiments for the Special Problems Committee. He designed and delivered more than one hundred electrically sustained gyros for torpedoes, enabling them to com-

plete extremely long trajectories, making hits on the target up to 16,000 yards.

Another most interesting and useful contribution by Mr. Sperry was a device which, whenever a submarine passed through a net suitably submerged and anchored, sent in an alarm by wireless. The "submarine alarm" consisted of an anchored net with submerged wireless buoys anchored at the bottom of the sea, and connected with the net at intervals so that when the net was "carried away" the nearest wireless buoy would be detached from its anchor and rise to the surface. Mounted vertically on the buoy was a tall mast having wireless antennas. Within the buoy, which was 37 in. in diameter, was a complete wireless outfit with an automatic key, each giving a different number. Some of these buoys were made and subjected to experiment in lower New York Bay, in the bay off Bath Beach, Brooklyn, and in Long Island Sound. Whenever the net was encumbered, a buoy would invariably come to the surface, float, and at once start to repeat a number—for example, 383, 383, 383—at intervals of a minute and a half, and keep it up for about one hour. The useful radius of the device was twenty to thirty miles. From Bath Beach the number was picked up on

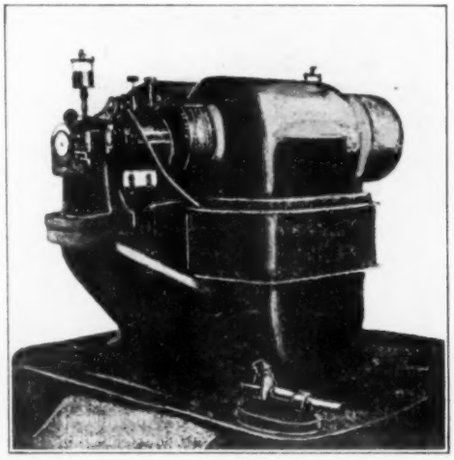


FIG. 9 EARLY TYPE OF ELECTRIC MINING GENERATOR

the antennas on top of the Sperry Building, at the Manhattan Bridge Plaza, Brooklyn, fifteen miles or so distant. (See Fig. 10.)

PROJECTION OF LIGHT THROUGH WATER

Mr. Sperry made a contribution also to the art of projecting light through water. This involved extensive construction and many tests. A clue was obtained from the work of the Prince of Monaco, that the myriads of animalculae in sea water give almost a total reflection of any light beam projected through it. It was determined that water is not like glass, as had been supposed. Instead of being able to project a beam of light through water, the beam is reflected by the animalculae. An experiment was conducted with a very large light, with 400,000,000 candlepower in the beam, using 150 amperes of electric current at 75 volts, condensed and directed by a 36-in. projector. The beam from the same light has been seen for 62 miles in the air. This light was placed in the bottom of a steel well, in which were several tons of lead, and in which a lateral window had been provided near the bottom, made from plate glass about one inch thick and forty inches in diameter. The well was about twenty-five feet deep, and was hung by a bale from a crane. Ladders were placed inside the well, and a switchboard, ammeter, voltmeter, and other equipment necessary to operate the light. (See Fig. 11.)

The light was first tested in the muddy water of the New York Navy Yard at a depth of ten or fifteen feet. It was noticed that there was a total reflection of the light, but this was attributed to the muddy water. It was observed that a sphere of light 80 ft. in diameter surrounded the window at the bottom of the well. It was brilliantly luminescent. This luminescence acted as a fog to obscure vision. Brilliance of luminescence seemed to be about the same at all points in this sphere, even exactly back of the well in the rear of the window through which the light was shining. After this experiment the clearest ocean water possible was looked for, and a bay at the end of Long Island was selected. The big barge with the heavy steel well dangling at the end of its crane was towed to this point and additional observations were made with naval officers present. It was found here also that the beam of light could not be projected through the water as had been hoped, and that a globe of luminescence was produced as in the experi-

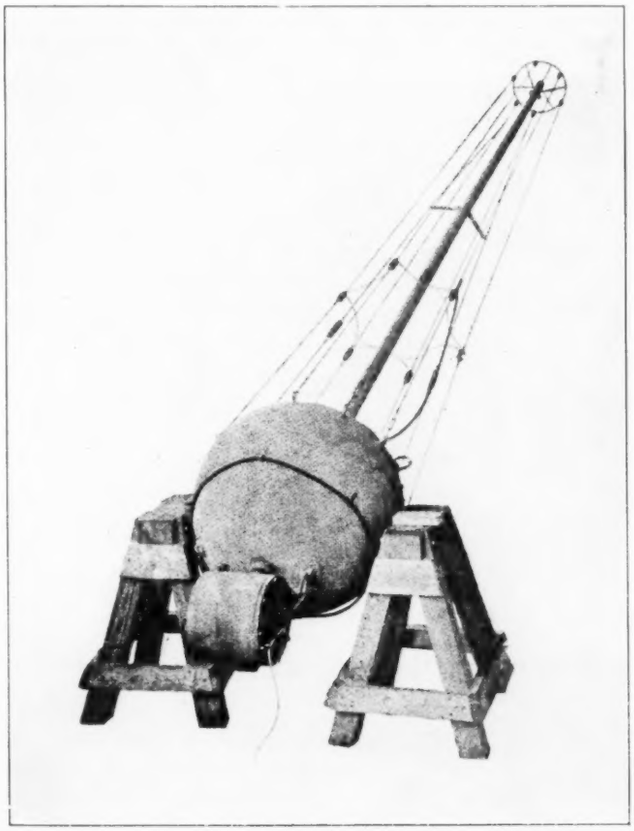


FIG. 10 AUTOMATIC SUBMARINE RADIO ALARM

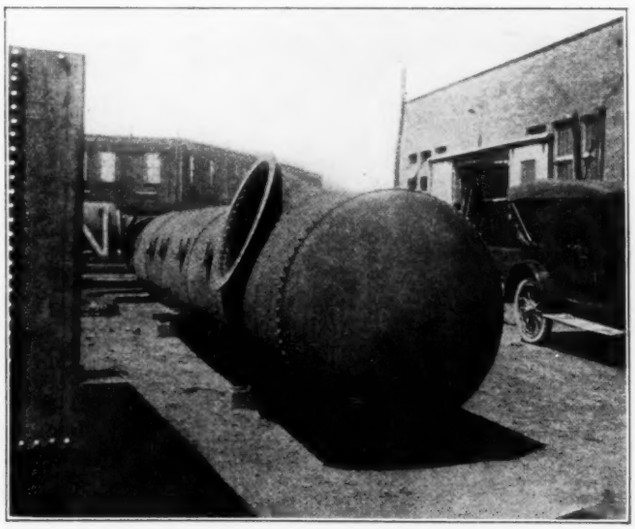


FIG. 11 APPARATUS FOR TESTING UNDERWATER ILLUMINATION

ments in the New York Navy Yard. The globe of luminescence was visible through this comparatively clear water for possibly a quarter of a mile, and could be used for the purpose of silhouetting mines, anchors, cables, and other things of this nature against its white background with great distinctness up to this distance. Obviously the presence of animalculae was the cause of this phenomenon of total reflection of the light.

Mr. Sperry further developed the goniometer, an instrument

for determining the altitude of an airplane when it is the target for persons on the ground, and the pretelemeter, a device for anti-aircraft gunners to determine the fuse setter's range and the exact position of a target in terms of azimuth and elevation, the latter having range deflection. Both of these devices were made and put into service.

He produced a searchlight for airplane defense, the problem being to throw the beam from the searchlight vertically without harm to the mirror. Up to the time that this was accomplished, 50 degrees had been the highest elevation at which it was safe to operate a searchlight.

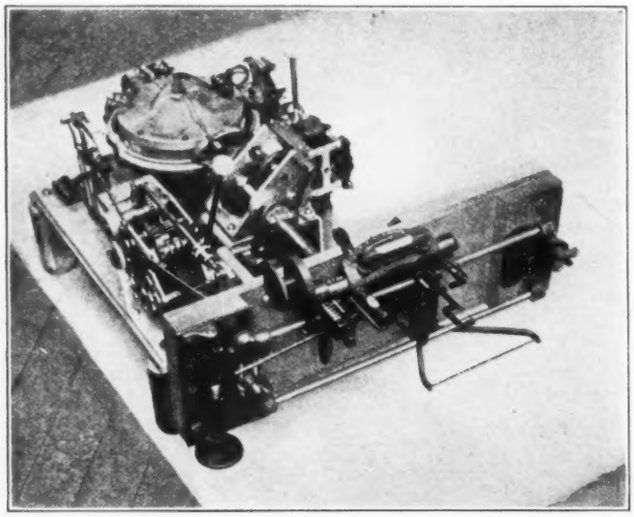


FIG. 12 BOMB-DROPPING SIGHTING DEVICE

FIG. 13 DEPTH CHARGE FOR SINKING A SUBMARINE. SETTING THE FUSE ON ONE OF THE SMALLER SIZES

BOMB DROPPING FROM AIRPLANES

Mr. Sperry devised two solutions for the problem of dropping bombs from airplanes. Anti-aircraft guns frequently drove airplanes so high that in dropping bombs it was almost impossible to reach a target. It had been humorously said that "they were fortunate if they hit in the same county." An automatic bomb dropper with a stabilizer equipment for handling the vertical components to a high degree of accuracy was completed and successfully tested, bombs being dropped with great exactness. The stabilizer on this device always pointed to the center of the earth, which was a great advantage to the pilot. (See Fig. 12.) The second solution used complete wireless control of a bomb as it was being dropped. The bomb was directed by wireless through an antenna attached to the bomb. Messages when received by the antenna would set in motion a mechanism which automatically adjusted another mechanism to direct the flight of the bomb. A big mark was placed on the top of the umbrella in the shape of an arrow, which could be seen from the airplane. This arrow was painted with aluminum paint, which is actinic, and was clearly visible on the black background of the umbrella. From an airplane the descending bomb looked like a big eight-foot ball with a fourteen-inch mark on it. This enabled the operators to direct it by the methods mentioned. In solving this problem many difficulties had to be overcome. The mechanism could be and actually was controlled over a distance of four miles.

AUTOMATIC DEVICE FOR FIRING AIRPLANE MACHINE GUNS

By another device of far-reaching importance the operator of a machine gun on an airplane, in combat with another plane, could introduce the element of range, and all the deflections necessary for hits. All airplane engagements up to the close of the war had been at point-blank range. The virtue of the new device was that the range would have been greatly extended, so that machine-gun fire would have been effective up to one thousand yards by automatic action. It should have given us control of the air, because the enemy's fire would not have been effective at the ranges at which we would have been able to score hits. The apparatus was entirely automatic and introduced all of the factors in the aiming of the weapon that the operator of the gun would be obliged to take into consideration. In its creation there was involved the introduction of all of the mathematical outside ballistics of the projectiles in the terms of angular velocity. An engagement between airplanes is so brief that it is impossible for a gunner to make the requisite calculations for all of his deflection factors, or any of them. The device was humorously called "the social secretary to the aircraft gun," in that it constantly made appointments for the gun with the distant, rapidly moving enemy aircraft.

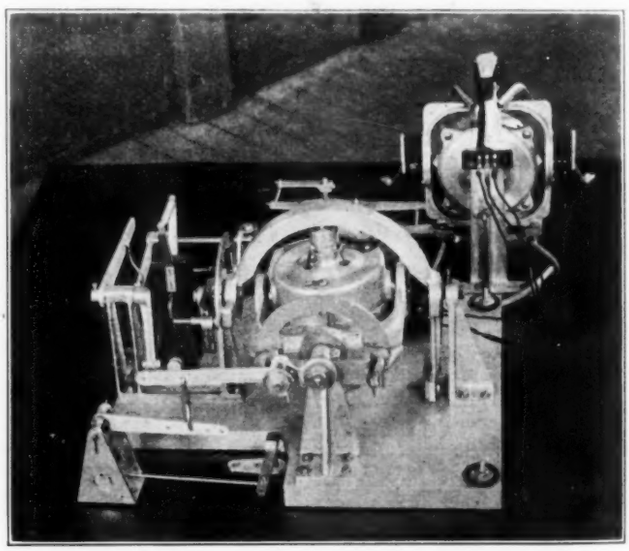


FIG. 14 GYRO MECHANISM FOR AN EARLY AERIAL TORPEDO

In this connection there was developed a remarkable gun sight so designed that it could be used perfectly by persons who do not know how even to shut one eye, and could permit a large angular deviation of the eye position; in other words, a large eye field, so that if the eye were anywhere within this field, the observation would be instantaneous as to where the target was in reference to the cross-hairs in the gun sight. The advantage of this sight is apparent when it is compared with an open sight, requiring in

order to be of the slightest use, exact alignment of the forward sight, the rear sight, and the eye.

With this gun sight the eye, bobbing around, as always in an airplane, could be in any position of the wide-angled eye field, for an automatic device was placed at the conjugate foci of the sight, bringing the range into the field of vision at all times, so that the gunner did not have to take his eye from the sight.

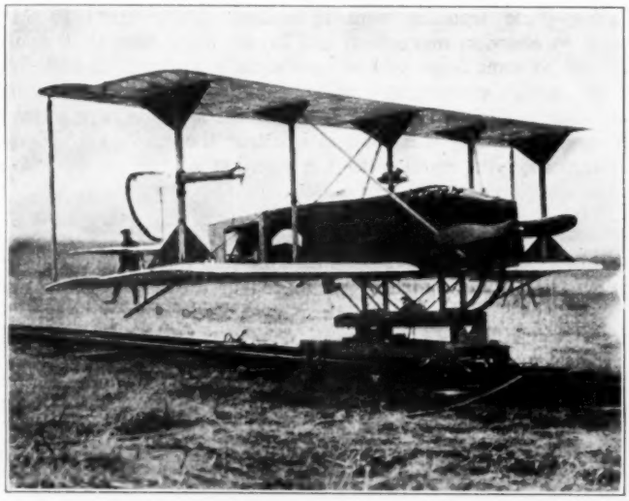


FIG. 15 AERIAL TORPEDO ON LAUNCHING AND DIRECTING RUNNER OF CATAPULT

propellers and the detection of hydrogen in submarines. Hydrogen is generated by the Edison storage batteries under certain conditions. The investigations were made in order to devise an automatic hydrogen detector which would give an alarm when two per cent of hydrogen was present in the air. The fact that hydrogen increases heat conductivity proportionally to the percentage of hydrogen was utilized by electrically energizing a small but highly radiant body.

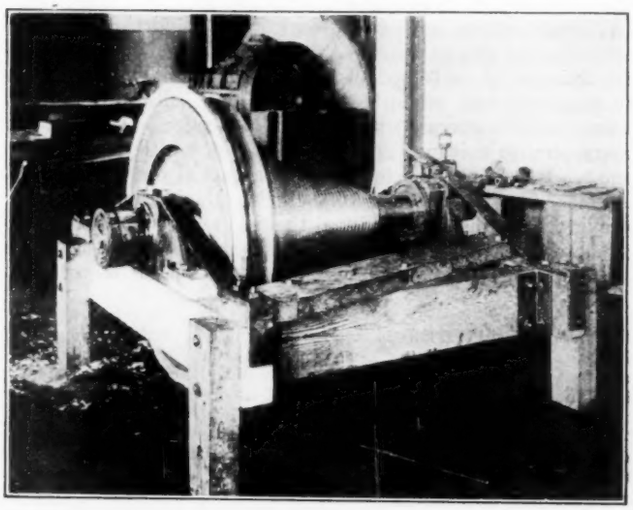


FIG. 16 MECHANISM OF CATAPULT FOR LAUNCHING AERIAL TORPEDOES

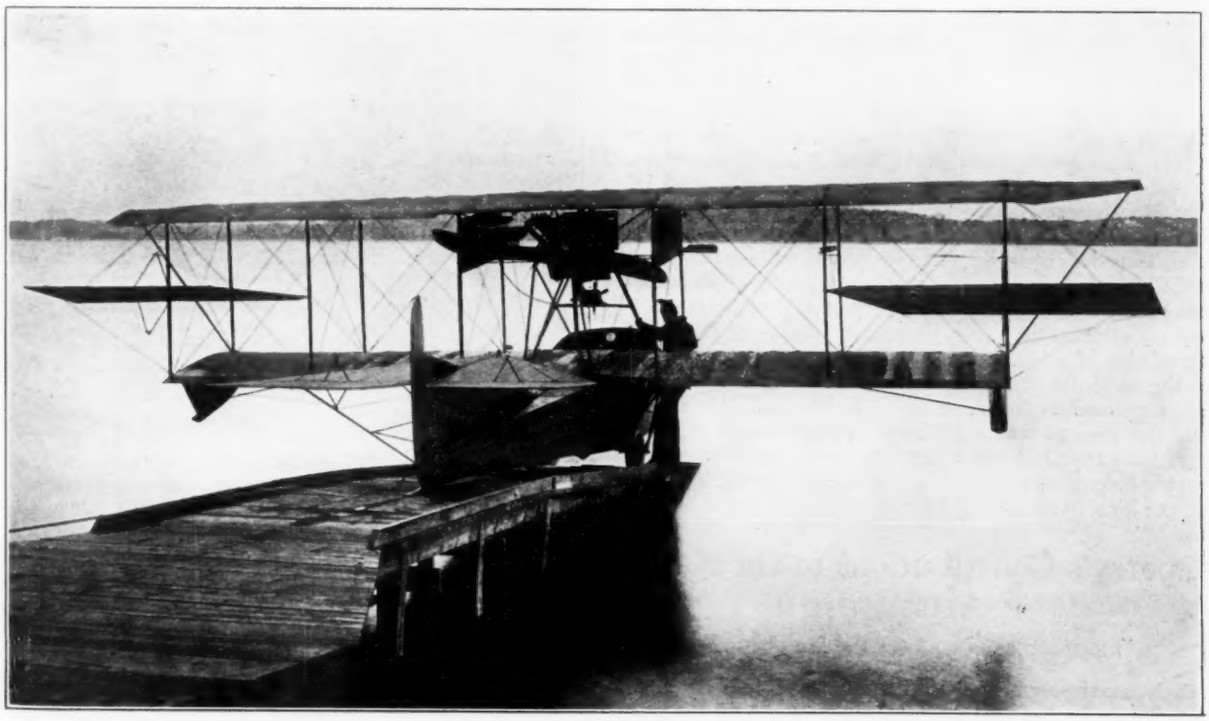


FIG. 17 ONE OF THE LARGER AERIAL TORPEDOES, WITH MR. SPERRY'S LATE SON, LAWRENCE, STANDING ALONGSIDE

SUBMARINE DESTRUCTION AND CAPTURE

Mr. Sperry and his force made valuable contributions to the art of depth charges for sinking submarines. The depth charge used generally by the United States Navy during the war was the result of suggestions by many men and institutions. The Sperry firing was tried experimentally on the first depth charges constructed in the United States. Mr. Sperry's organization and plant were requisitioned to manufacture the first 10,300 depth bombs made in America for our Navy. (See Fig. 13.)

He devoted a great deal of attention to the construction and use of submarine nets, and did painstaking work on steel airplane

AERIAL-TORPEDO DEVELOPMENT

One of Mr. Sperry's most intense activities during this period was his manufacture and tests of aerial torpedoes at Sperry Field, near Copiague, Long Island, which was held under guard by marines. The first seven were full-size J. N. Curtiss planes and many tests showed complete automatic control with a high degree of accuracy at a target 35 miles distant, but they were organized to function to about three times this distance. (See Fig. 14.) The torpedoes rose to a predetermined height, then automatically leveled off for the flight, were automatically guided with a high degree of precision, and, when any predetermined miles and fractions had been

traversed, suddenly turned and flew vertically downward. Each carried a very large charge of TNT, with sensitive contact fuses—enough, in fact, to blow up a fortress or an ammunition dump, or, in the words of one of the admirals, to "blow a small town inside out." Lawrence Sperry had practical charge of much of this work, together with a retired naval officer, Commander McCormick, requisitioned for this special duty. The work was held in extreme secrecy; the nearby townspeople understood that the field was simply a training camp for aviators.

A power catapult and aiming device that could be quickly disassembled and put on board a truck was also devised. The catapult delivered these torpedoplanes into the air at flying speed at the exact required azimuth, with wind and ballistic corrections. It was found to operate with practical perfection. The source of energy, strange as it may appear, consisted of a little 4-hp. gasoline engine. It was possible to discharge an aerial torpedo every six minutes. (See Figs. 15 and 16.) Trubee Davison was appointed to review these tests. He visited the field a number of times and became enthusiastic over the results he saw. Part of a statement he made about a long non-stop flight test of one of the torpedoes is quoted.

> I remember [said Mr. Davison] the first actual flying test that they made. They took a Curtiss land machine, removed the landing gear and put the plane on a small truck which ran along a track and constituted a catapult. The plane was set to climb at an angle of five degrees and, after it had flown about five thousand yards along the ground, to dive and crash. Some of the leading men from the Navy Department were on hand. They had the motor started and gave the sign to pull the trigger. The truck shot forward and the plane rode up. It encountered puffs of wind and was controlled as though an experienced aviator was on board. When it reached the point where it was to dive, something went wrong with the diving mechanism and the plane went right on by and went up out of sight to the sky, climbing all of the time. They never found a trace of it afterward.

After work at Sperry Field had been going on for some time the Army started a similar development of torpedoes with smaller planes at Dayton, Ohio. Mr. Charles F. Kettering and the Dayton engineers came to the Sperry factories, canvassed the whole matter in detail, and took with them all the essential gyroscopic equipment. Then Mr. Sperry traveled to Dayton about every two weeks to aid in this activity, which was carried on with high intensity by Mr. Kettering and his fine corps of assistants. At the time of the armistice, quantity production had been started on these aerial torpedoes to be delivered in France. Since then they have reached a high degree of perfection and a number of torpedoes have been made, tested, and delivered. (See Fig. 17.)

Mr. Sperry's versatility, resourcefulness, indefatigability, and broad knowledge of science and engineering were of inestimable value to the nation in the time of peril. His war services were a natural supplement to his numerous and highly valuable contributions to the peaceful arts. To this simple statement of a few of the medalist's technical achievements I would add appreciation of Sperry, the helpful man, the interesting companion, the inspiring associate, the loyal friend.

III—Sperry's Contributions to the Naval Arts

BY REAR ADMIRAL BRADLEY A. FISKE[3]

MODERN naval progress received its principal impetus from the building by England of the *Dreadnought*, soon followed by the *Delaware*, our proud exhibition ship at the last English coronation. With their high speeds, long-range guns, and armored protection against enemy shell fire, these ships represented a great advance. Although as powerful and efficient as engineers could make ships, their guns were limited in effectiveness to short range because of the very considerable rolling of the vessels and because it was still necessary for the gun pointer to see the target before firing. This was the situation when Mr. Sperry was asked to aid the Navy on a number of problems.

Mr. Sperry was blessed with three sons. When his children were young he brought to them all sorts of gyroscopic toys, even importing some. He was known to have accumulated a library on the gyroscope, with which he had always been fascinated. He had become familiar with the actual magnitudes of the gyroscopic reactions, apart from theory. He had intimated to the Navy that he believed he could overcome the intolerable troubles due to the magnetic compass with larger and larger masses of steel in ships. The magnetic compass not only possessed certain vagaries, but had become treacherous, for it gave no indication of the magnitude of the error of its erratic readings. In submarines these troubles were intensified. It occurred to Mr. Sperry to abandon magnetism and invent a compass that would be based on some other field of force equally available at all points on the earth's surface, and not be disturbed by the conditions inevitable in all iron ships. The Technical Division of the Navy believed Mr. Sperry was right in selecting the gyroscope and depending upon its reaction to the rotation of the earth, which was just beginning to be appreciated.

SPERRY'S FIRST GYRO COMPASS

After trials on a New York merchant ship on the Norfolk run, Sperry's first gyro compass was placed in the powder magazine of a destroyer at the New York Navy Yard. Here it was surrounded by steel walls. No magnetic compass could have functioned,

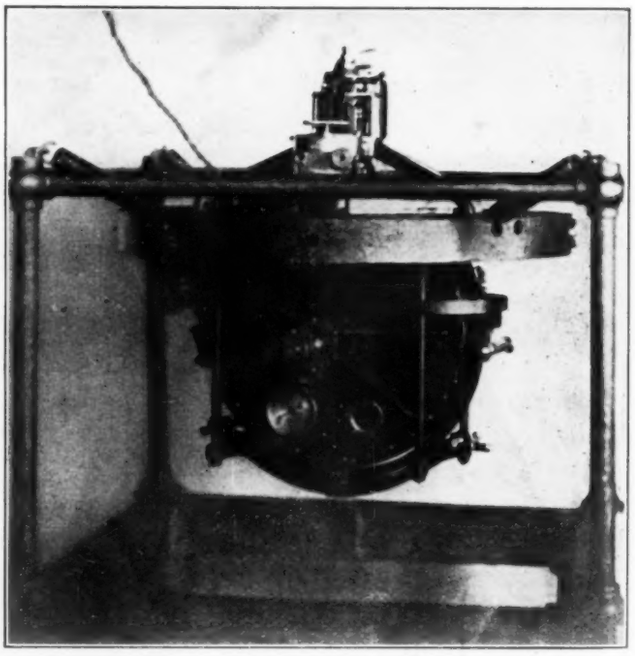


FIG. 18 COMPASS ON THE "DELAWARE"

but the gyro placed there functioned, and sea trials proved it to have extraordinary accuracy. These trials included a high-speed run which necessitated firing the destroyer's forward boilers. This test was delayed several days because the heating of the smokestack nearest the bridge had put all the magnetic compasses out of business. Their errors were as high as 20 deg., so that extreme measures had to be adopted to get them back on to the magnetic meridian. Mr. Sperry's compass had been provided with an automatic corrector for all conditions of the highest speed, so this test proved as completely successful as the other tests had been. These tests demonstrated that the gyro compass dealt uniformly with true chart azimuths and with absolute geographical meridians, under all conditions, instead of with the erratically placed magnetic meridians, which converge at the magnetic pole, 1800 miles from the real pole which must be used in all navigation.

After these trials, Mr. Sperry's first gyro compass was installed on the *Delaware* in 1911. (See Fig. 18.) Connected with the master compass were two repeaters, one used for steering and the other for taking bearings and observations. With this small equipment as a beginning, it was not long before a recorder (Fig. 21) was arranged to record the angle of the ship's head from the true north. The integrity of the pointing of the gyro compass and its utter

[3] United States Navy, Retired.

refusal to take up any of the yawing movements of the ship were such that it established a base line which was soon utilized by means of other instruments for control of turret guns in azimuth, and eventually was permanently established as the foundation of the whole gun-control system.

Soon after the successful trial of the experimental compass in the *Delaware*, the Navy placed a contract for eight compasses for the first-line ships. The *Utah*, just being completed at the end of 1911, was the first vessel in the American Navy fitted with a

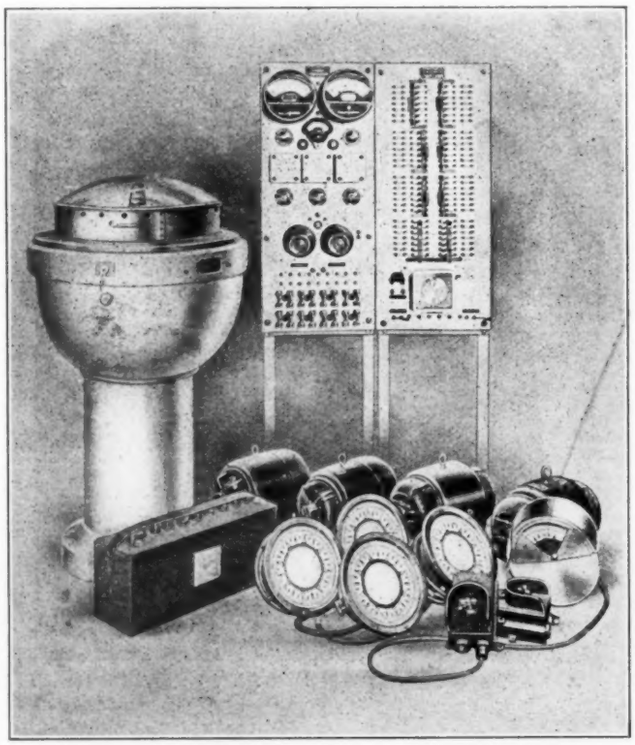


FIG. 19 COMPLETE COMPASS EQUIPMENT, INCLUDING SWITCHBOARD, MASTER COMPASS, AND REPEATERS LOCATED AT DIFFERENT POINTS IN SHIP

new complete gyroscopic compass equipment (see Fig. 19). Following this installation all battleships and submarines were rapidly equipped. About two years later, the standard Sperry gyro compass was taken up by the British, Japanese, French, Italian, and Russian navies in the order named. When the World War started, all the Allied navies were equipped. In the merchant marine the gyro compass has been adopted by steamship companies for the navigation and automatic steering of the ships (Fig. 24) of about a hundred fleets.

Along with the gyro compass and its auxiliary equipment, the voltage regulator was developed, particularly for use in submarines. This instrument gives a constant voltage to the compass regardless of the variation in the supply-line voltage, which usually has a wide range in submarines. The gyro compass made the submarine practically useful, because without it submarines are practically helpless. Magnetic compasses are inoperative in submarines because, in addition to the steel hull, there are two strong magnetic fields: (1) from the powerful electric motors necessary for submerged maneuvering, and (2) from heavily loaded direct-current cables. In addition to serving as a navigational means, the gyro compass in the submarine gives a permanent base line for firing torpedoes.

TARGET-BEARING AND TURRET-CONTROL SYSTEMS

Soon after getting the gyro compass started, Mr. Sperry developed the target-bearing system. He placed a target-bearing transmitter in the foretop on the mast and a plotting indicator in the plotting room for giving three indications: (1) the angular bearing in azimuth of the target from the ship's head, (2) the bearing of the ship's head from the true north, and (3) the direct reading in true chart azimuth of the bearing of the target. This was an important advance in serving the heavy turret guns of battleships. From this point on it was possible to make hits on targets that were definitely over the horizon and impossible to sight from the turrets themselves, although under observation from the fighting top more than 100 ft. above the water line.

To enhance the rapidity of serving turret guns, the next step logically taken by Mr. Sperry was the turret-control system (Fig. 20) of indicators in the turrets operated from transmitters in the plotting room. The target bearing as given by the target-bearing system is set on the turret train transmitters with the necessary deflection, spotter's correction, and other refinements introduced, so that by a clever arrangement of pointers originated by Mr. Sperry, known as the follow-the-pointer system, the guns could be fired for the first time in salvo and hits made without the turret trainer being able to see the target. As the Aid for Operations of the Navy at the time, it was my pleasure to be associated with Mr. Sperry. He has always been appreciative of the parts taken

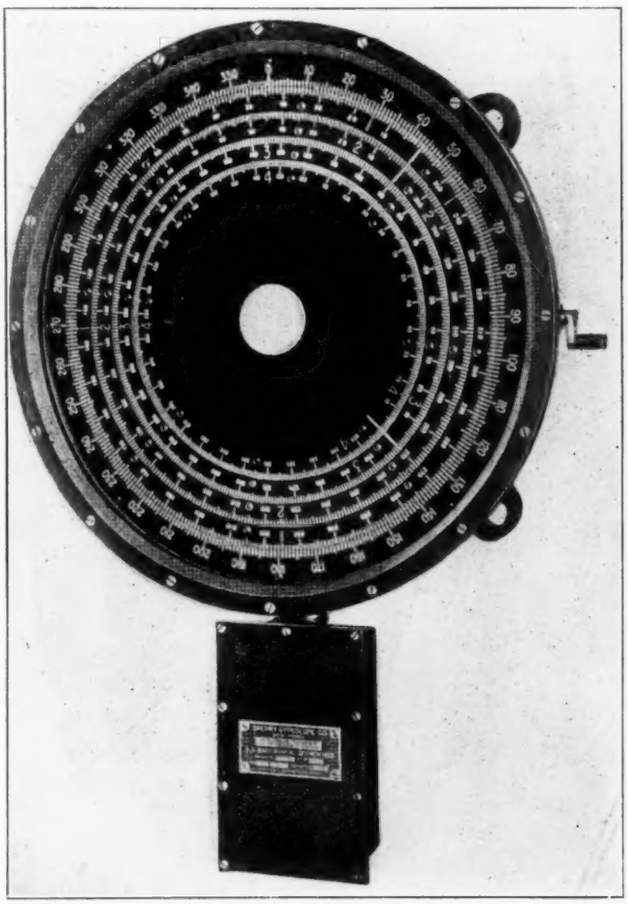


FIG. 20 ONE ELEMENT OF TURRET-CONTROL SYSTEM

by myself and other officers in making this important advance in gunnery. This arrangement permitted the grouping of guns for starboard and port firing as well as training all guns on a common target. This system (Fig. 22) also included a transmitter operated from the rack of each turret that showed accurately the position of the turret and indicated in the officer's control room the position of his own and adjacent turrets, which prevented firing in the danger zone. It also indicated to the Chief Fire Control Officer in the plotting room on a multiple turret indicator whether the turrets were all firing on the designated target. The firing could thus be instantly suspended in any turret not found "on," and its expensive ammunition saved.

BATTLE-TRACER SYSTEM

With our vessel and the enemy vessel both moving at high speed on their different courses, including the intricate maneuvers of each, it is necessary that the courses of the two vessels together with the range and their respective speeds be plotted. To record

the exact positions of both ships during all maneuvers, Mr. Sperry invented the battle-tracer system (Fig. 23), which automatically records on a chart the ship's speed and course, and, simultaneously on the same chart the course, speed, and position at any instant of the enemy ship. This permits close prediction of enemy bearing and range so that hits can be made regardless of the maneuvering of either vessel, allowance being made also for the time of flight of the projectile. This system has been used even through barrages and smoke screens. By leaving off the enemy arm, the battle tracer becomes an excellent dead-reckoning-tracer system. It has been widely adopted and comes under the cognizance of the Bureau of Navigation.

RANGE-FINDING DEVICES

From 1912 to 1917, several other important contributions to naval efficiency were made by Mr. Sperry. They include the optical range indicator system, which permits the ranges shown on the range finder to be automatically introduced into the control system and the gyroscopic directorscope, which represented the beginning in our Navy of a well-established system of director

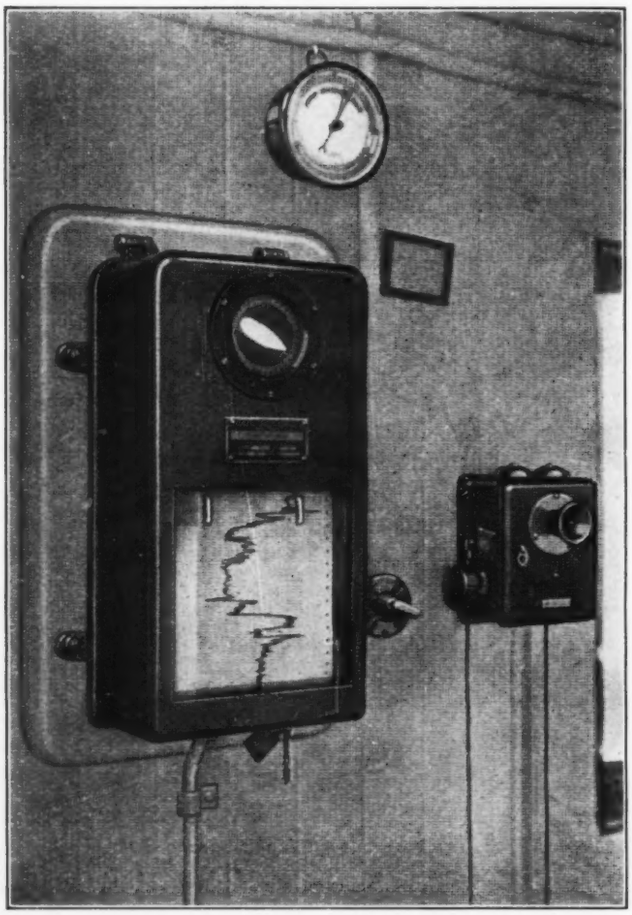


FIG. 21 COURSE RECORDER AS INSTALLED

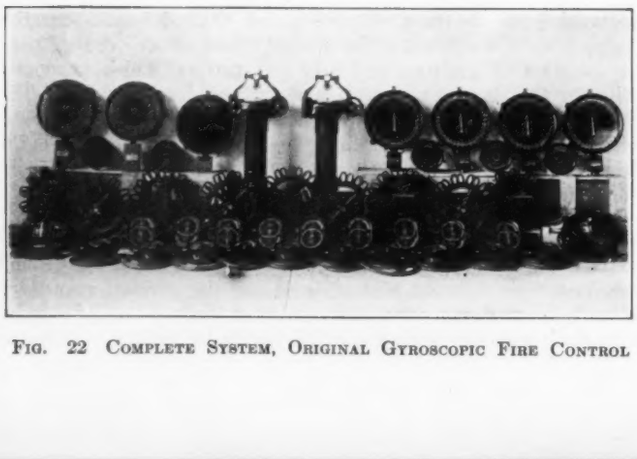


FIG. 22 COMPLETE SYSTEM, ORIGINAL GYROSCOPIC FIRE CONTROL

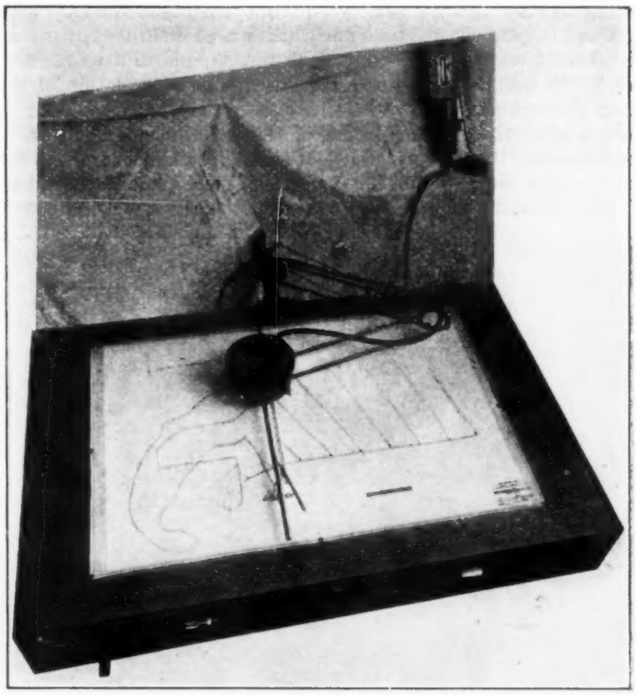


FIG. 23 BATTLE TRACER ON CHART, SHOWING ENEMY ARM

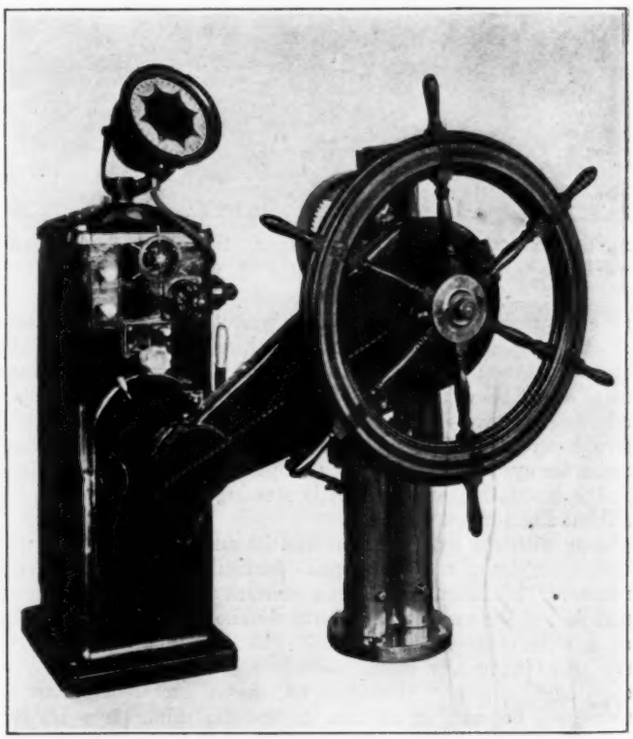


FIG. 24 GYRO PILOT, KNOWN AS "METAL MIKE"

firing. It was my pleasure again to be associated with Mr. Sperry on some of this work.

In 1914 Mr. Sperry developed the long-base range finder, which used the full length of the ship. Mounted at each end of the ship were protected telescopes forming the terminals of the base line. The integrated results appeared automatically in the plotting room. It was installed on the *Delaware* for trial. Testing equipment for accurately adjusting torpedo gyroscopes was made by Mr. Sperry in 1915, and the electrically sustained torpedo gyro about this time. The latter maintains a constant number of revolutions per minute, neutralizing the rotation of the earth and thereby practically doubling the range and accuracy of torpedoes.

In 1912, a number of gyroscopic roll-and-pitch recorders (Fig. 25) were made for Admiral, then Captain, Taylor, who distributed them among the battleships on their notable voyage to the Mediterranean, encountering two terrific storms. Many thousands of feet of record showing accurately the exact performance of each ship, especially as to the individual increments, in both roll and pitch during these storms, constitute the first important information of this kind available to the Navy.

SPERRY'S WORK IN DEVELOPING THE GYROSCOPIC SHIP STABILIZER

Mr. Sperry's early work on the gyroscope led to the observation that the directional power employed in the compass was only one

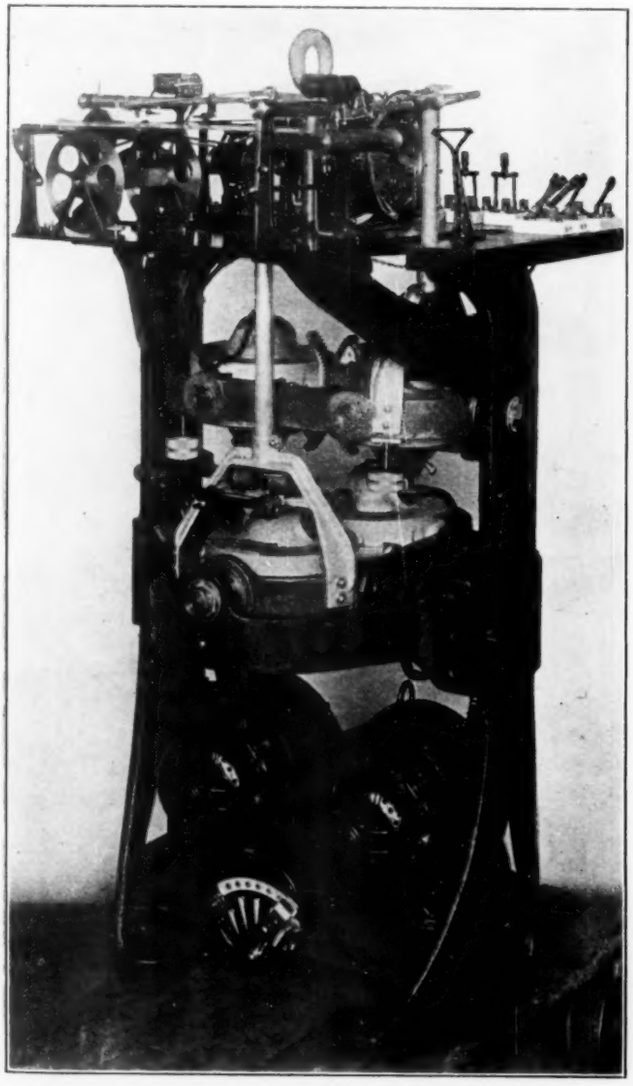


FIG. 25 ROLL-AND-PITCH RECORDER—ORIGINAL HEAVY TYPE

of its major contributions. It has another useful power, which Mr. Sperry often refers to as the "muscle" of the gyro, the reaction available for the stabilization of any oscillating body, such as a rolling ship. Beginning with the first tests of ships' models in tanks by that Nestor of naval experimentalists, the elder Froude, it came to be recognized that ships rolled freely, the energy of the roll being insignificant at its beginnings, before the individual wave increments by their cumulative effect had built up wide-angle rolling. Both energy and roll due to any single wave increment were insignificant. Realizing this fact, Sir Philip Watts was the first to provide means for suppressing roll, installing his device on two battleships early in the eighties. Naval architects and engineers have followed with many attempts to reduce the rolling of ships. It was realized that if the incipient energy of each wave increment could be anticipated by corresponding reaction, the ship could be easily prevented from all beginnings of rolling and therefore would never roll, save slightly. Mr. Sperry, with the active type of gyroscope, created and properly timed the anticipatory reactions, and gaged their power to meet each wave increment as it arrives. This method involved artificial precession of the gyroscope even on a non-rolling ship while maintaining a level deck. It was an outstanding achievement.

At the Washington Navy Yard the first experiments on gyro stabilizers were made with a model (Fig. 26) built by Admiral Taylor, the active type of gyroscope being furnished by Mr. Sperry. It was my good fortune, as member of the General Board of the Navy, to secure the recommendation of that Board to the Secre-

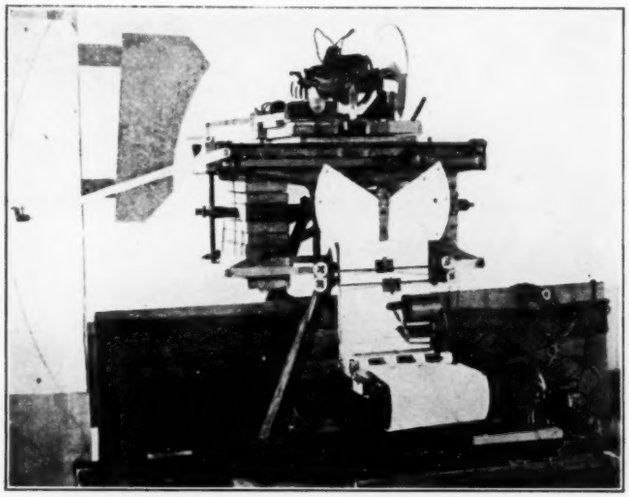


FIG. 26 ADMIRAL TAYLOR'S ORIGINAL SHIP'S MODEL WITH RECORDING MECHANISM FURNISHED WITH ACTIVE TYPE OF GYRO STABILIZER

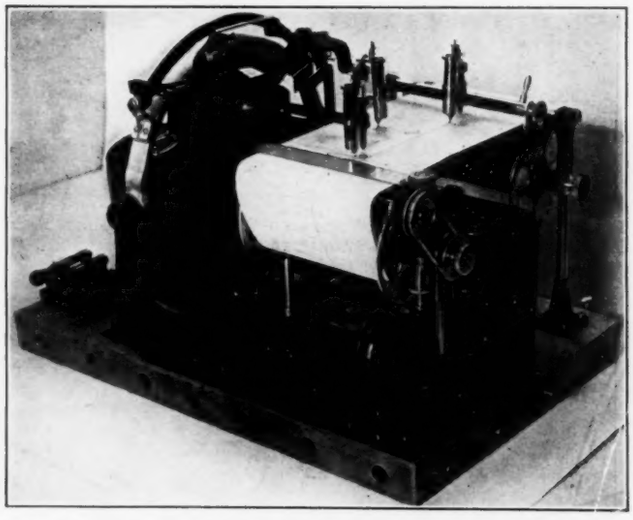


FIG. 27 ROLL-AND-PITCH RECORDER—PRESENT LIGHT TYPE

tary of the Navy that such a trial be made. Automatic records showed that the stabilization of the model was highly efficient. Sea trials followed. Experimental equipment was ordered by the Navy in 1911 to be placed temporarily on the destroyer *Worden* at the New York Navy Yard (Fig. 29). A little reversing engine automatically controlled by a small pilot gyro (Fig. 30) was used to produce the artificial precession. On all recent equipments the precession motor has been a standard reversing electric-elevator motor with brakes, causing the gyro to oscillate between the two positions shown in Figs. 31 and 32. These trials gave thousands of feet of record indicating complete suppression of roll even under extreme weather. Other important observations included the fact that as soon as the vessel was stabilized, it would stop shipping seas and its decks would become dry. Still more important, it was also established that when entirely free from roll, the ship

was also entirely devoid of stresses. All groanings and other weird noises of the rolling ship invariably ceased completely when it was stabilized. Calculations by naval architects in different countries all prove conclusively that this is exactly what should have occurred, because even the heaviest seas can perform on work on a non-rolling ship.

FIG. 28 GROUP OF PITCH AND ROLL RECORDS

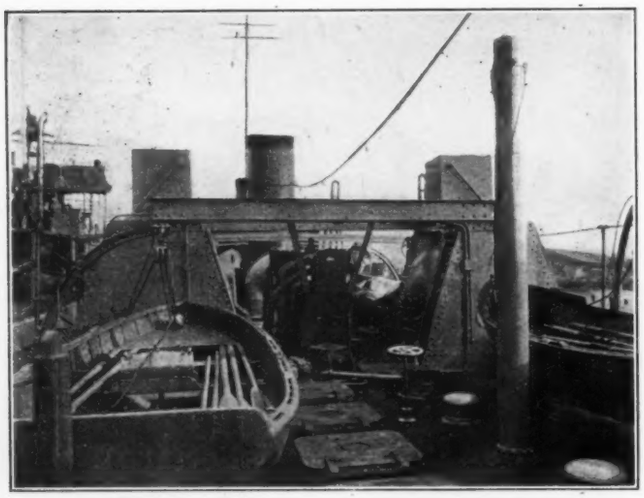
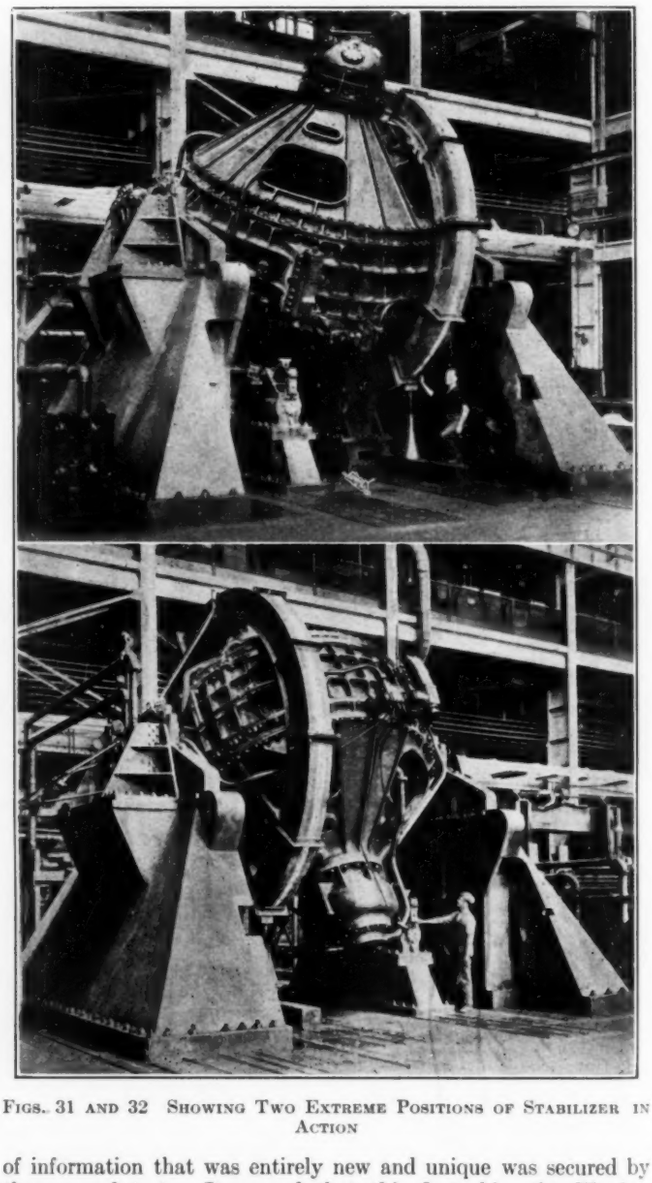


FIG. 29 DECK OF "WORDEN" SHOWING FIRST SEAGOING EXPERIMENTAL EQUIPMENT OF ACTIVE-TYPE STABILIZER. SMALL REVERSING PRECESSION ENGINE SHOWN IN MIDDLE OF BACKGROUND

FIG. 30 PILOT GYRO FOR CONTROLLING THE PRECESSION MOTOR

This was the first time that a ship was ever under complete control. By opening a single little switch, as large as a pocket knife, this control could be removed, with the result that she would roll to the seas terrifically, allowing all kinds of observations to be made at different angles to the waves and at different speeds. Yet this rolling could be suppressed entirely in about five oscillations by the simple closing of this same switch! The masts would gradually assume the vertical position and then remain so with the same heading, the same speed, and the same angle to the waves. Conditions could be maintained as long as desired while studying the whole phenomenon, accurate records being taken by the roll-and-pitch recorder of every motion of the ship, both rolling and stabilized, for critical examination. A great amount of information that was entirely new and unique was secured by these naval tests. It proved that this first ship, the *Worden*, had succeeded in coping with each individual wave increment coming from either side and was able to develop counter moments which completely neutralized wave effect, so that the rolling did not have an opportunity to build up. It was definitely found that all co-periodic rolling was completely suppressed. This means that gyroscopic moments had been provided that were adequate to meet the rolling moments of the largest single wave increments ever reaching the ship, even in extremely heavy and stormy seas, and that this balance of forces is the only requisite for complete suppression of the roll of any ship.

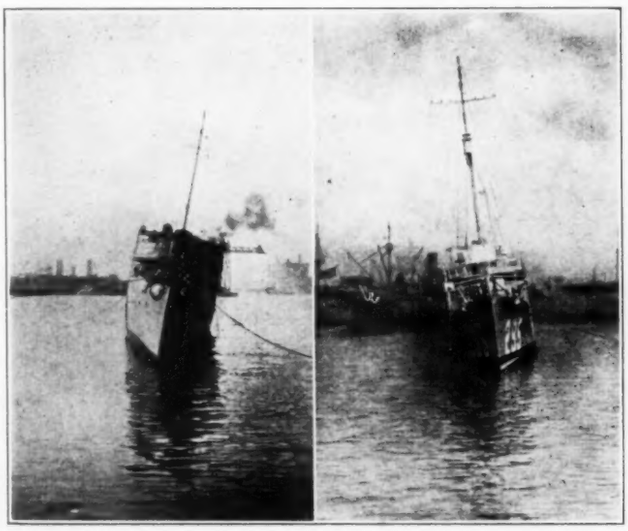


FIGS. 31 AND 32 SHOWING TWO EXTREME POSITIONS OF STABILIZER IN ACTION

Before this installation was made, Sir William White was invited to give his opinion as to the magnitude of the strains and stresses delivered to the ship by the gyroscope, in the effort to suppress roll

completely. His report was interesting as well as gratifying; he stated that the moments so delivered were practically insignificant, required, as they are, to neutralize single wave increments only and being of the order of a slight fraction of the stresses naturally set up in every ship whenever it rolls. Extensive experience with this factor since those early times has shown that in very large ships the gyroscopic moments represent only about two-tenths of one per cent of the normal bending moments in a ship rolling through an angle of about twenty degrees. So Sir William White was correct in his assurance that there need never be any fear on this account. This conclusion is in accordance with the universal understanding now that the sea cannot get hold of a non-rolling ship or do any appreciable work on it. It is found in practice that the stabilizing moments imparted by the gyro to the ship to make it completely non-rolling are very small.

Another fact ascertained from the *Worden* equipment was that it was a matter of indifference to the stabilizer whether it rolled the ship in still water or held it against rolling in heavy weather. A number of motion pictures and photographs were taken of the *Worden* being rolled up to high angles by her gyro



FIGS. 33 AND 34 THE "WORDEN," 700 TONS, AND THE "OSBORNE," 1750 TONS, BEING ROLLED BY THEIR GYROS IN STILL WATER

equipment. This possibility is useful for ice breakers and in the Navy for training gunners on rolling ships. Rolling may be practiced on yachts also on occasion, to entertain the guests in calm weather. (See Figs. 33 and 34.)

Two other installations were later undertaken by the Navy, one on the *Henderson* and the other on the *Osborne*, but the specifications for these ships had to be radically altered after the stabilizers were built, making them much heavier and stiffer ships. Though the roll-and-pitch recorder showed that these equipments performed their functions and delivered to the ships stabilizing moments in excess of those specified in the contract, yet the ships themselves were so greatly increased in tonnage and metacentric height that the gyros were inadequate to stabilize them completely in heavy weather. The stabilizers were able to roll these ships to a high degree, however, and gunfire experiments were conducted on both ships with promising results.

Learning of this work in the United States, and being cautioned about the importance of certainty as to the ship's final characteristics, both the English and the Italian navies have made installations that have been completely successful. The naval equipment in Italy has been tested with expert gunners in extremely heavy weather with surprisingly good results. Incidentally it was found that while the stabilized ship was firing regularly, it was impossible even to serve the guns on her two sister ships in the same storm, with the same heading, maneuvers, and speeds.

The largest gyroscope in the world installed on board ship was put to unique service by the Japanese Navy, as part of the equipment of a large airplane carrier, the *Hosho*, a ship that can be burdened from 10,000 to 12,000 tons but with the usual high metacenter which is the practice with all navies. (Fig. 35.) This ship did not have to be altered after the contract was made so as to augment its stabilizing characteristics. After four years of operation, very satisfactory results have been reported. In weather so heavy that other ships of the fleet of corresponding characteristics were reported as rolling nineteen degrees on a side, the roll of this ship was known to be under two degrees. When the *Hosho* was rolling naturally to the seas through an arc of twenty degrees on a side, she could be stabilized and brought under perfect control. Usually in about six oscillations she rolled only about two degrees. In all this performance it was found necessary to run the gyro wheel at only fractional speeds. The normal speed of this wheel

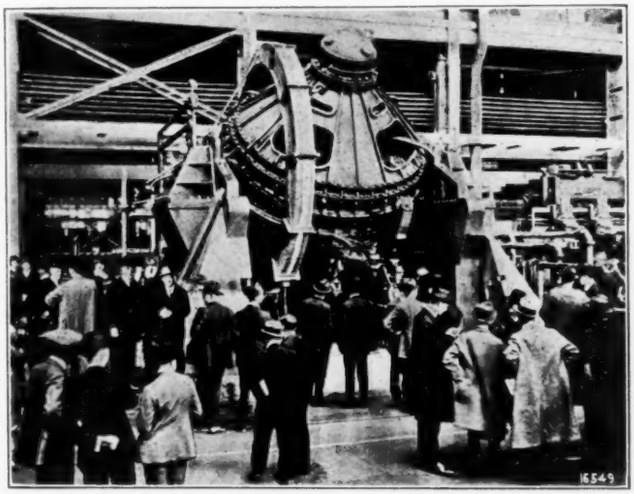


FIG. 35 STABILIZER FOR JAPANESE NAVY IN ACTION IN THE SHOP

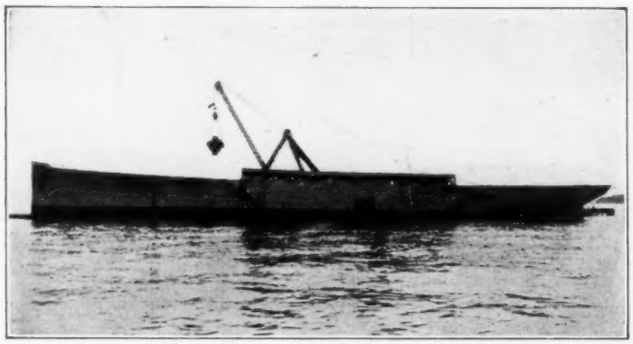


FIG. 36 EQUIPMENT ILLUSTRATED IN FIG. 35 ON THE CRANE, BEING LOWERED INTO PLACE, SHOWING RELATIVE SIZE OF EQUIPMENT AND SHIP

in its acceptance tests in America, Mr. Sperry states, was 815 revolutions per minute, but the results mentioned were obtained at about 80 per cent of this speed. This installation, owing to the great metacentric height of the *Hosho*, corresponds to a normal merchant-marine ship of about 16,000 tons. The rotating element weighs considerably less than one-half of one per cent of the displacement, the whole plant being insignificant in size compared with the ship and requiring only a small amount of power for its operation. (See Fig. 36.) I understand this plant has not been reviewed by Mr. Sperry or any of his engineers since its installation.

Many yachts, also, have been fitted with gyro stabilizers during the past few years, additional evidence that complete stabilization of ships has now become an established fact. The pioneer work will certainly lead to the adoption of this device for both naval and passenger service. It will make an extremely important contribution to both, but especially in the Navy to accuracy of gunfire and facility to serve the guns. It will also increase the usefulness of airplane carriers.

PALLOGRAPHS

In 1915 Sperry built a pallograph (Fig. 37) for the Navy, and afterward a second one. These proved to be extremely valuable

instruments for the detection of all kinds of vibration on shipboard, in buildings, and in other structures. By means of this instrument the exceedingly perplexing and repeated breakage of the tail shafts of the *Maryland* class of battleships was traced to its origin and remedied. With a much cruder apparatus of this kind an alarming vibration in the aft quarter of the *Lusitania*, developed on her trials, was finally completely suppressed. Serious vibration and swaying of tall buildings have also been traced to their origins and methods devised for their suppression.

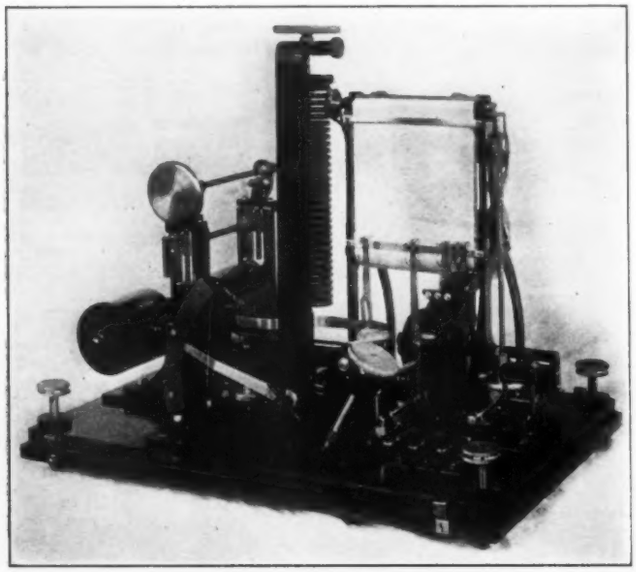


FIG. 37 SPERRY'S PALLOGRAPH

FIG. 38 HIGH-INTENSITY ARC BEING PRODUCED BETWEEN CARBON TIPS

THE HIGH-INTENSITY-ARC SEARCHLIGHT

Mr. Sperry's earliest commercial venture was in arc lighting. With that start he has followed all advances in this art. Our Navy in 1914 had ascertained that with the largely increased range of guns and collateral advances in the naval art the best searchlight then employed was so outdistanced as to become obsolete. It revealed one's own position far more than it aided in detecting the enemy. This state of affairs was talked over with Mr. Sperry. He told the Navy Department that he felt sure he could change this whole situation by greatly increasing the light intensity and also concentrating the beam so as to reduce dispersion. The outcome was Mr. Sperry's high-intensity arc (Fig. 38) of 1915, which gets illumination of about eight times the beam candlepower out on the target. The most efficient searchlight then known delivered 25,000 beam candlepower per pound of weight of searchlight. With his searchlight we get today a beam candlepower of 900,000 per pound weight of searchlight, an increase of thirty-six times.

Dr. Michelson found in his experiments on Mt. Wilson for measuring the velocity of light that the specific intensity of this arc transcends the luminosity of the sun's radiation reaching the earth in the proportion of 920 candlepower per square millimeter of the sun's surface to 1140 or 1200 for the high-intensity arc. Mr. Sperry has recently furnished to both the Army and Navy searchlights that have become standard for defense against aircraft at night, for all coastwise defense, and for many other uses. He has produced a super-searchlight for anti-aircraft defense with an excessively powerful beam stated by Government officers to be no less than two billion candlepower (Fig. 39). The Air Mail also uses powerful beacons of these lights as guides for its pilots across the continent at night. Making a mechanism that would control the high temperatures of the arc was also an engineering achievement of very great importance.

Descriptions of Mr. Sperry's many contributions to the advancement of the naval arts cannot be compressed into a brief statement. In the foregoing paragraphs it has been possible only to outline a few of his outstanding achievements in this field alone. He is a real inventor. Many persons who have been called inventors have only devised improvements or adaptations of the work of other men. Sperry is one of a very few men of actual originality, and one of an exceedingly small band who have made true discoveries and brought them into the realm of the mechanic arts and utilized them for the benefit of mankind. He has seen visions and has embodied his visions in useful forms.

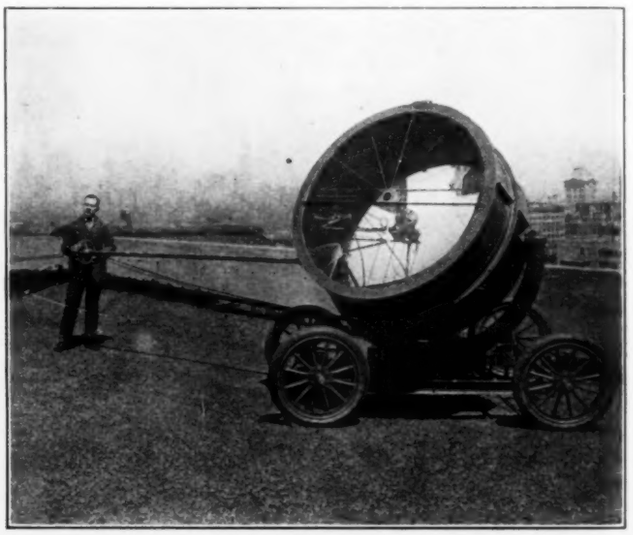


FIG. 39 LARGEST TYPE OF SEARCHLIGHT WITH 60-IN. MIRROR, PORTABLE TYPE

One of the many sardonic fruits of the World War is a new mode of progress in business which has been discovered for stubborn Europe. Their plants having been demolished by the Germans during the war, the Belgian steel men set about to install the newest construction. Since their new mills have been in operation they have produced steel so cheaply that it can be exported into England and sold considerably cheaper than English steel, which is made in old mills, greatly overmanned. The English, says *Advertising and Selling*, not having had their old mills wilfully destroyed, cling to them as if they were precious heirlooms.

What a wonderful opportunity for the imagination to guess how much the world would be advanced if its obsolete equipment of every sort were suddenly forcibly taken from it by fire, the ruthless destroyer! England is bestirring herself to modernize, but finds it hard to "scrap." The operation is painful, but it must obviously be performed, either by voluntary action or by fire, earthquake, or catastrophe.—*Mechanical World*, December 3, 1926, p. 442.

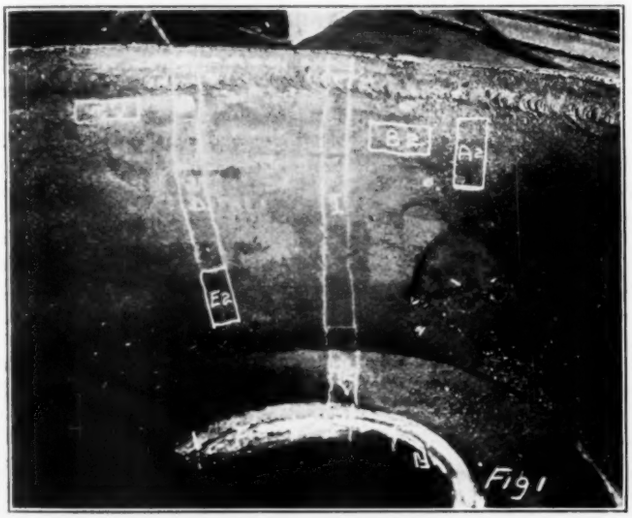
Examination of the Ruptured Head of the Ethylene Tank

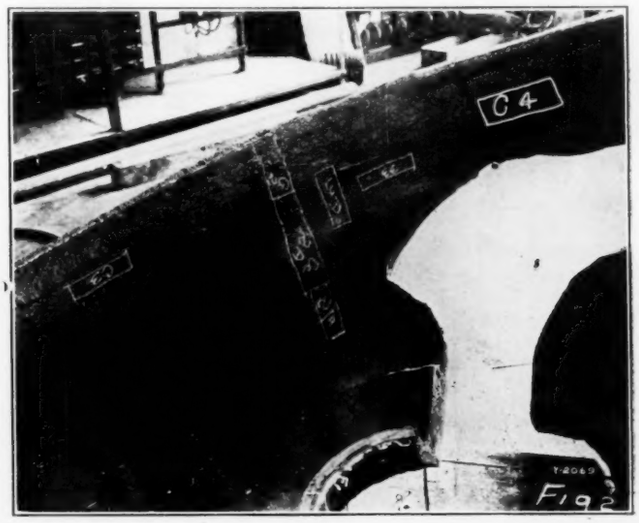
Description of Test Pieces Taken—Macro and Micro Photographs—Chemical Analysis—Tensile Tests—Microstructures—Conclusions Regarding Welds, Weld Metal, and Test Pressure Used on Tank

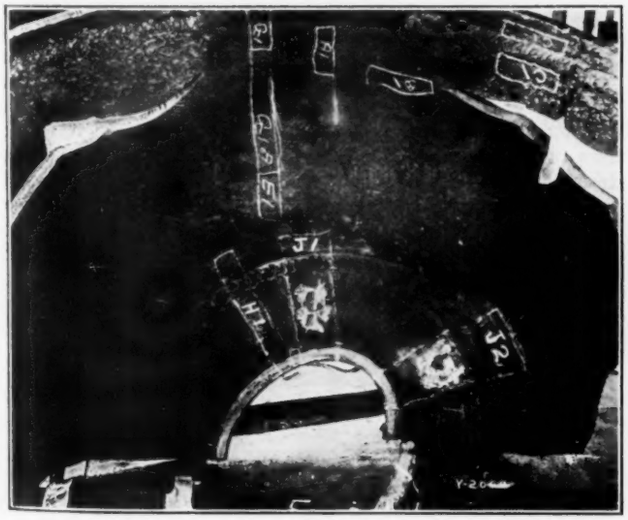
By S. W. MILLER,[1] LONG ISLAND CITY, N. Y.

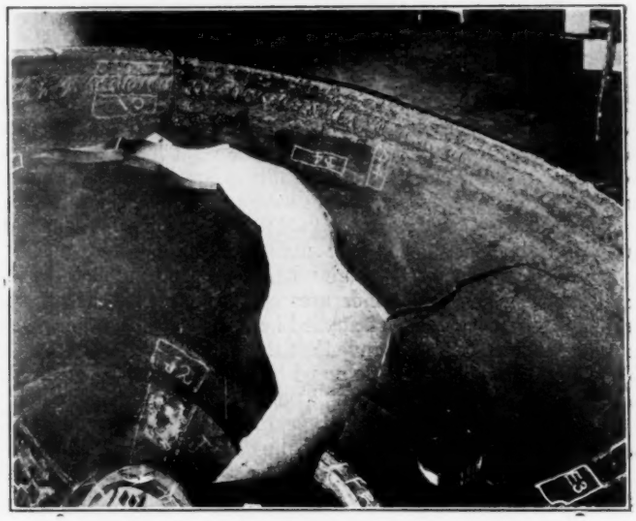
A GENERAL report of the circumstances leading up to the rupture of this head was made on June 30, 1926, and published in MECHANICAL ENGINEERING for August, 1926, pp. 845–846.

The ruptured head was cut off with a cutting torch about two inches beyond the head girth weld and sent to the Union Carbide and Carbon Research Laboratories for investigation and study. After careful consideration by all those interested, it was decided that the best method to pursue in the investigation was to take tensile test pieces from various parts of the head to see if any change had been made in the physical properties by the various processes to which the head had been subjected. It was also decided that sections should be cut from various parts of the head to determine what change in thickness had been caused by the flanging operation, and that a number of macro and micro sections should be examined, as they might explain changes in physical properties, as well as show the general quality of the welds. Chemical analyses were also decided upon, to be made from the head, the shell, and the manhole flange.









FIGS. 1–4 PARTIAL INTERIOR VIEWS OF TANK HEAD SHOWING POSITIONS OF CERTAIN SAMPLES BEFORE REMOVAL
(See Fig. 5 for assembly drawing.)

In accordance with these ideas the general location of the test pieces was marked off with chalk on the head, and photographed as in Figs. 1 to 4, inclusive. While these photographs show the original chalk marks they do not show them all on one view, and in order that there may be more definite understanding of the exact relationship, Fig. 5 has been prepared, giving these all on one sheet. Of course Fig. 5 shows the test pieces as if they were in the undamaged head, but it is believed that this will make it more clear than could be done in any other way.

[1] Union Carbide and Carbon Research Laboratories. Mem. A.S.M.E. Presented at a joint meeting of the Metropolitan Section and Machine-Shop Practice Division of the A.S.M.E. with the New York Section of the American Welding Society, New York, January 4, 1927.

After these photographs and drawings were completed, additional "C" and "C-A" samples were taken. These of course do not show on any of the views, but occupy the same relative position as others of the same type.

General Description of Test Pieces

The letter preceding a number may be termed a classification letter, and the number indicates the serial number of the test piece, several of each kind being taken in order to get a fair average from similar locations in the head.

The "A" pieces were taken longitudinally of the tank and the "B" pieces close to them radially of the tank. There were four of each.

The "C" pieces were taken in the head as close as possible to the bottom of the vee of the girth weld in order to determine any effect that the heat might have had on the base metal. There has been considerable discussion in the past in regard to this heat effect, and this appeared to be a good opportunity to obtain some exact information. There were also some pieces marked "C-A" that were taken from the weld metal in order to see what its characteristics were, and to determine as closely as might be whether the welding had been well done. These pieces were taken from the same sections as had been cut out for the "C" pieces and less than one inch away from them, as shown in the small view in Fig. 5.

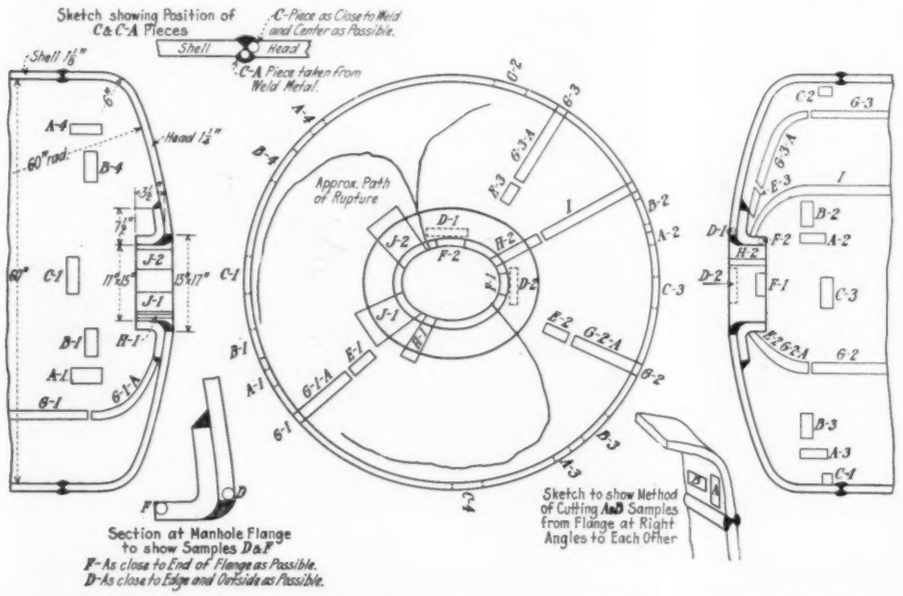

Sketch showing Position of C & C-A Pieces
C-Piece as Close to Weld and Center as Possible.
Shell
Head
C-A Piece taken from Weld Metal.
Shell 1⅛"
Head 1¼"
60° rad.
Approx. Path of Rupture
Section at Manhole Flange to show Samples D & F
F-As close to End of Flange as Possible.
D-As close to Edge and Outside as Possible.
Sketch to show Method of Cutting A and B Samples from Flange at Right Angles to Each Other

FIG. 5 ASSEMBLY DRAWING SHOWING POSITION OF ALL TEST SAMPLES TAKEN AS THEY WOULD APPEAR IN TANK HEAD BEFORE RUPTURE

Two pieces marked "D" were taken from the head close to the ends of the major and minor axes of the manhole. There was probably more welding heat applied here than at any other place, and it was thought that if any effect therefrom were to be found it would be there, and might be noted by the microscope. In addition to this there would be but little, if any, effect such as exists when a weld is of the double-vee type, in which case the grain of the first side welded is refined by the welding heat from the second side. It was also considered important to know if the stretching that had occurred at the manhole had affected the strength of the material at that point.

The three "E" test pieces were taken at a point as remote as possible from any welding heat, about half-way between the flange and the manhole. It was thought that these would offer a good basis for comparison.

Two pieces marked "F" were taken from the flange of the manhole plate, to get some idea of the physical properties of the metal, as it was not of exactly the same characteristics as the head and shell.

The "G" sections were taken to show the change in thickness of the metal due to flanging. There were three of them. For the same reason the two "H" sections were taken.

The section marked "I" was taken entirely through the flange of the head, the weld, and the shell, partly to determine as accurately as possible the radius to which the head had been distorted. It was taken at a point where the least distortion due to the rupture had occurred.

There were two sections taken marked "J" for the purpose of determining if any residual stresses could be found due to the weld. It was doubted that this could be done because of the permanent set that had been undergone by the head during the testing, but it was considered worth trying. All these sections were cut out with the cutting torch, but were cut very large in order to remove any possibility of the heat causing any effect on the metal.

Photomacrographs

These are shown in Figs. 6 to 14, inclusive. In the "C" specimens the ends were etched, Figs. 6 to 9, inclusive, to determine the general quality of the welds with regard to penetration and thoroughness of fusion. There are a few minor defects at the bottom of the vee, but they are unimportant because they are small and local, and because they are more than made up for by the reinforcement.

In Fig. 6, showing section "C-1," the layout of the tensile test pieces "C" is shown. While it looks as if the test pieces were out of center with the center line of the section, yet the center of the length of the test piece is central with the center line, the curvature of the piece making it necessary to offset the stub ends of the test piece. It might also be remarked that the "C-A" test pieces were taken close to the "C" test pieces in the weld metal, and Fig. 6 shows how close these are together.

Figs. 13 and 14 show the thicknesses at various points of the sections taken through the manhole flange. Evidently the original thickness of the plate from which the flange was made was $1\frac{1}{2}$ in., which has been reduced by the flanging operation until it is only slightly over $1\frac{1}{4}$ in. where the manhole plate fits. This points to the necessity of taking into account this change in thickness and calculating the strength of the actual flange, and not assuming that the manhole flange has its nominal thickness. The "G-A" and "I" sections are shown in Fig. 15, with the dimensions at various points. As the material was rough, the accuracy of the last decimal figure is not very great, but it is given as determined by the average of three readings.

The head was intended to be $1\frac{1}{4}$ in. thick, but it will be noticed that in no case was this dimension obtained in the spherical part of the head, although the minimum thickness is only about 0.04 in. less than $1\frac{1}{4}$ in. In general, the head seems to have thinned down in the spherical part and to have gradually thickened up toward the knuckle, until an increase in thickness is seen amounting in section "I" to 0.18 in. at the end of the flange.

As far as the author knows, the general impression has been that the material is thinned down at the knuckle by the flanging operation; and this may be true when the flanging is done at one stroke by complete dies in a flanging press, which is the practice always followed in large shops for production. It is, however, general practice in any shop where only one or two heads are needed, to use a sectional flanging press to do the work, and if the operation of such a machine is considered, it appears that there is an upsetting of the metal at the flange as it is gradually turned, instead of the stretching which would be expected to occur when the head is forced at one time through a circular die.

It therefore appears that this matter should receive further consideration, and that in each case the type of machine used and the method followed in making the head should be known.

As to the effect on the welding of this thickening of the flange, it seems to emphasize the necessity of more beveling of the head on the inside so that the section of the vee on the head and on the shell are closely the same, especially with heavy plate.

The inside radius of the knuckle in section "I" is 5¼ in. as taken from the outline of Fig. 15. In Fig. 1 of the original paper above referred to (see MECHANICAL ENGINEERING, August, 1926), this inside radius is given as 6 in. Later information states that this radius was 6 in. outside, which checks fairly well and really as closely as can be expected with the actual radius in section "I,"

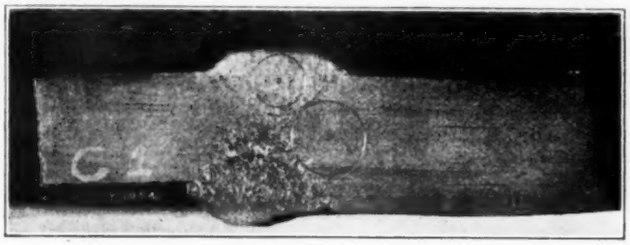


FIG. 6 MACROSCOPIC VIEW, FULL SIZE, SHOWING WELD BETWEEN HEAD AND SHELL AT POSITION "C-1"

(Note the good fusion of the weld and base metal, also the refinement of the grains on one side of the weld from the welding heat of the second side. The two circles denote the positions of the "C" and "C-A" samples. These were taken respectively from the base metal immediately adjoining the weld and from the weld metal itself.)

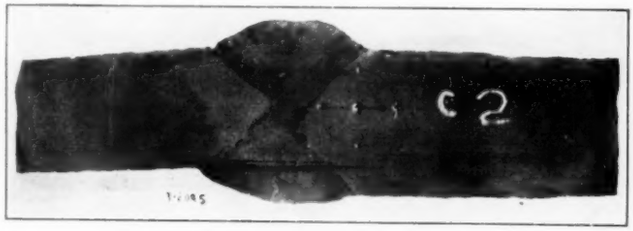


FIG. 7 MACROETCHED AND PHOTOGRAPHED, FULL SIZE. TAKEN FROM POSITION "C-2" IN FIG. 5

(Note the position of the inscribed circle as close to the weld metal and to the outside face of the tank head as the curvature will permit. All the "C" samples were taken in this general way.)

FIG. 8 MACROETCHING OF WELD AT POSITION "C-3"

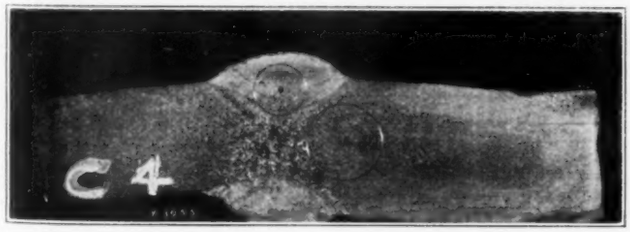


FIG. 9 TAKEN FROM POSITION "C-4," FIG. 5. MACROETCHED TO SHOW POSITION OF WELD METAL

because it is doubtless true that the distortion due to the testing altered this radius to some extent, and as there is always the question whether the head when flanged and cold exactly fitted the flange blocks.

The radii of the "G" section have not been measured because of their manifest distortion by the rupture.

CHEMICAL ANALYSES

	Mill test	Laboratory Tests		
		Head	Shell	Manhole flange
Carbon, per cent	0.18	0.22	0.09	0.17
Manganese, per cent	0.42	0.40	0.32	0.43
Phosphorus, per cent	0.011	0.018	0.013	0.010
Sulphur, per cent	0.030	0.033	0.019	0.020

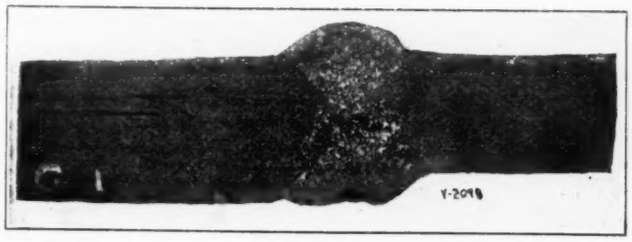


FIG. 10 MACROETCHING OF SAMPLES SHOWN AT POSITION "G-1" IN FIG. 5 TO SHOW QUALITY OF WELD

FIG. 11 MACROETCHING OF SAMPLE TAKEN AT POSITION "G-2" IN FIG. 5. NOTE THE GOOD FUSION ALONG ALL SCARF SURFACES

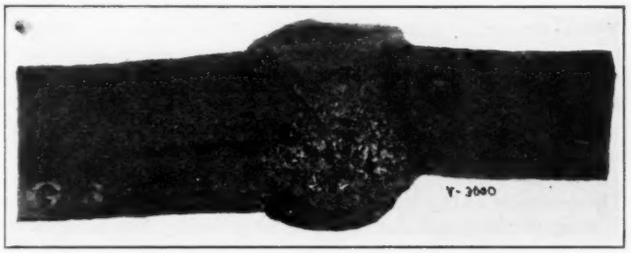


FIG. 12 MACROETCHING OF SAMPLE TAKEN FROM POSITION "G-3"

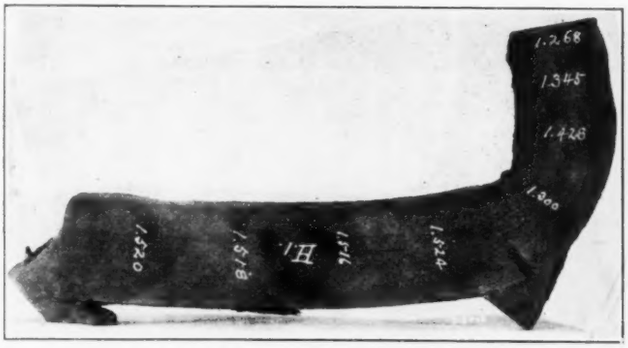


FIG. 13 MACROETCHING SHOWING THE THICKNESSES OF THE MANHOLE FLANGE AT DIFFERENT POSITIONS AND SHOWING CLEARLY THAT AT THE KNUCKLE OF THE FLANGE THE THICKNESS HAS BEEN REDUCED BY 0.2 IN.

FIG. 14 MACROETCHING SHOWING THE THICKNESSES OF THE MANHOLE FLANGE AT DIFFERENT POSITIONS

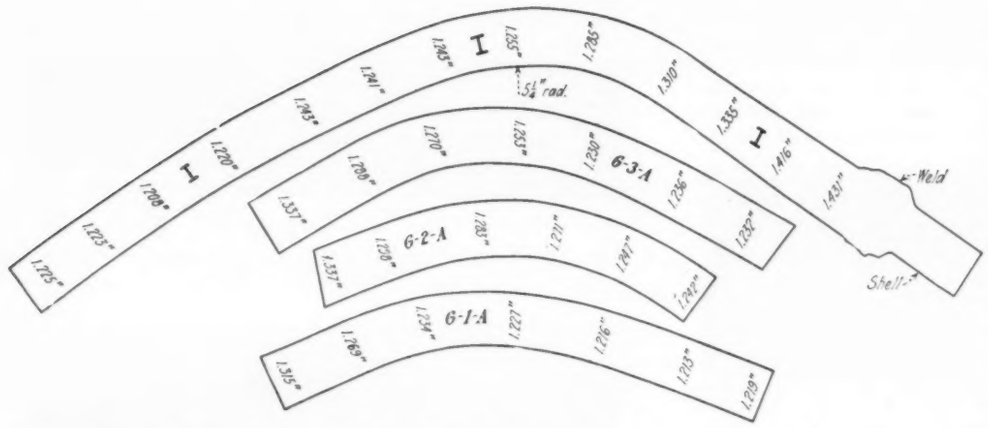


FIG. 15 DRAWING SHOWING THE EXACT CURVATURE AND VARIATIONS IN THICKNESS OF TEST SAMPLES TAKEN FROM DIFFERENT SECTIONS OF THE TANK HEAD AT THE RESPECTIVE POSITIONS SHOWN IN FIG. 5

All these are within the limits of the specifications for steel in the A.S.M.E. Boiler Construction Code, Section II.

TENSILE TESTS

Table 1 gives the results of the tensile tests, and it is seen that all of the test pieces from the head, regardless of their position, meet the requirements of firebox and flange steel in the Boiler Code in regard to tensile strength, yield point, and elongation, with the exception of test piece "A-1," which fails in the elongation by only 0.8 per cent. All of the reductions of area are also entirely satisfactory. The A.S.M.E. Pressure Vessel Code permits the use of the materials in Section II of the Boiler Code for the construction of pressure vessels.

The results of the "C" specimens show that, at least in double-vee welding in plate of this thickness, there is no change in the physical properties of the metal due to the welding heat. For many years one of the arguments of those opposed to welding has been that the base metal next to the weld must be injured by the welding heat. These results seem to show that there is no such effect.

In a number of instances, especially in the "D" and "E" test pieces, the yield point is considerably higher than in the case of the other pieces. The "D" pieces were taken close to the edge of the manhole and both the tensile strength and the yield point are higher than the rest of the plate, while there is some decrease in the elongation and reduction of area. It should be remembered that the area from which these pieces were taken was heavily cold-worked by the stretching, and while, as will be referred to later, the microscope shows no particular evidence of this distortion, yet it is well known that stretching beyond the yield point produces the results given by these test pieces. Therefore, while there is no definite proof of the cause of these changes in physical properties, it is not unreasonable to suppose that they are due in large part to the cold work, and it is perfectly safe to say that at least the material has not been injured.

TABLE 1 TENSILE-TESTING RESULTS ON COUPONS TAKEN FROM DIFFERENT POSITIONS IN RUPTURED ETHYLENE-TANK HEAD

Mark	Yield point, lb. per sq. in.	Ultimate strength, lb. per sq. in.	Per cent elongation	Per cent reduction in area	Remarks
	36,500	57,440	30.25	..	(a)
A-1	38,600	58,280	25.0	68.2	
A-2	36,750	59,950	32.5	62.6	(b)
A-3	37,800	57,650	38.5	62.6	
A-4	37,800	59,150	28.5	61.3	
B-1	43,650	58,700	33.0	64.7	
B-2	36,200	58,850	36.0	65.4	(c)
B-3	36,300	55,750	39.5	63.5	
B-4	41,400	60,100	35.5	62.8	
E-1	42,800	57,650	31.5	63.0	
E-2	40,800	59,250	32.5	59.8	(d)
E-3	49,500	63,800	28.0	58.8	
C-1	36,200	56,650	36.0	62.1	
C-2	37,400	60,900	34.0	59.1	
C-3	35,900	61,100	34.0	58.8	
C-4	35,500	58,500	38.0	60.1	
C-5	34,900	59,800	23.0	40.4	(e)
C-6	37,400	61,300	32.5	58.6	
C-7	32,400	59,600	34.0	59.8	
C-8	35,400	57,800	34.0	61.8	
C-9	37,900	60,800	37.0	61.3	
C-1-A	48,600	65,300	17.0	33.3	
C-2-A	50,900	71,100	8.0	18.75	
C-3-A	46,150	55,200	5.5	..	
C-4-A	43,700	61,200	6.0	5.22	(f)
C-5-A	47,000	63,300	12.0	29.4	
C-6-A	(x)	46,150	(x)	(x)	
C-7-A	48,000	65,100	25.0	39.3	
C-8-A	46,150	55,200	3.0	8.3	
D-1	53,400	64,100	29.0	57.8	(g)
D-2	45,700	62,150	26.0	57.0	
F-1	30,200	55,350	38.0	62.1	(h)
F-2	29,200	53,850	34.0	61.3	

(a) Mill test of head plate.
(b) Taken from head flange parallel with tank axis.
(c) Taken from head flange perpendicular to "A."
(d) Taken radially half-way between hole and knuckle.
(e) Taken from head close to weld and parallel with weld axis and outside tank surface.
(f) Taken from weld metal and parallel with direction of weld.
(g) Taken from head at manhole close to edge and outside.
(h) Taken from flange of manhole flange and as near edge as possible.
(x) Defect in test piece.

FIG. 16 SHOWING ALL THE "A," "B," AND "C" TENSILE SAMPLES AFTER TESTING

(The white lines shown on "A-1," "B-4," and "C-3" are shown in Figs. 20, 21, and 25 as micro sections, and in each of these cases are taken at right angles to the direction of testing.)

In considering this matter of strength it should be remembered that the whole head was badly distorted even before it ruptured, and that the rupture increased the distortion in many places. It is of course impossible to say how much distortion occurred at any one place due to the rupture, but it is quite possible that the change in physical properties of the "E" pieces can also be partly explained by the cold work occurring from this distortion, although no definite conclusions can be stated.

The manhole flange shows somewhat less tensile strength and yield point than, and about the same elongation and reduction of area as, the head, and the macroetching shows that they are of about the same quality, there not being enough difference between them to comment on.

The specimens taken from the weld metal show good strength and quite satisfactory properties, and are much better than many would expect. (These as well as the other test pieces are shown in Figs. 16, 17, and 18.) While most of these samples appear to have broken approximately in the center of the reduced section of the tensile sample, a few of the breaks appear to have been initiated at some slight defect. It must not be forgotten that such defects are not the same as those due to a serious lack of penetration or uniformly poor fusion, but that they are small and local and have but little effect on the strength of the structure as a whole. The author is not attempting to minimize, but to avoid exaggeration. It is also true that similar small defects are common in steel plate and that definite allowance is made for them in all standard specifications.

The examination of the "J" pieces does not give any definite information. Fig. 19 shows the location of the gage marks and the stresses that were found. The stresses are also given in Table 2. These stresses are the result of measurements taken before and after the pieces were cut out, and might be considered to indicate a partial release of the stresses due to welding, testing, and rupture, each of which would seem to have had some effect.

The figures show that in all except one case, "J_2T_1" in Table 2, the radial and tangential stresses were opposite to each other as would be expected, but in many cases they are so different in value that they could not be considered of definite import. It must also be remembered that the removal of the pieces may have introduced some stresses, although care was taken to cut them as large as possible. With the same exception as referred to before, the stresses in the head and in the saddle plate are opposite to each other in sign, although widely different in value. Everything considered, the author does not see that it is possible to draw any quantitative conclusions in regard to these stresses.

MICROSTRUCTURES

A few photomicrographs have been taken from the tensile-test-piece stubs and are shown in Figs. 20 to 26, inclusive. There is no serious difference in the structures except in Fig. 23, taken from the weld metal, in which the structure is coarser as would naturally be expected. The weld metal seems to have about the same carbon content as the base metal. It would also be expected that the metal just next the weld would be somewhat coarser, and Fig. 25 shows that this is the case, although the grain is finer than might be looked for. The structure being quite regular, although having some patches in which the pearlite is distributed differently from what it is in most of the area, would seem to account for the lack of change in the physical properties. Fig. 26 taken from the manhole flange shows a much more strongly banded structure than either the head or the shell, and apparently contains less pearlite than the head; the chemical analysis confirms this belief.

TABLE 2 RESIDUAL STRESSES AROUND MANHOLE IN TANK HEAD AND SADDLE PLATE IN FAILED HEAD OF ETHYLENE TANK

(Stresses in lb. per sq. in. between welds)

Location	Tank head	Saddle plate
J_1T_1	5,100 Tension	23,000 Compression
J_1T_2	9,000 Tension	15,100 Compression
J_1R_1	1,200 Compression	17,100 Tension
J_1R_2	16,500 Compression	10,200 Tension
J_2T_1	15,700 Compression	14,800 Compression
J_2T_2	16,500 Compression	13,900 Tension
J_2R_1	14,800 Tension	13,300 Compression
J_2R_2	12,200 Tension	10,700 Compression

FIG. 17 PHOTOGRAPH OF FURTHER SAMPLES WHICH WERE TENSILE TESTED AND WHOSE POSITIONS IN THE TANK HEAD ARE SHOWN IN FIG. 5
(The light lines shown on "E-1," "D-1," and "F-1" are the positions of the micro sections shown in Figs. 22, 24, and 26, and all are discussed under their respective figure numbers.)

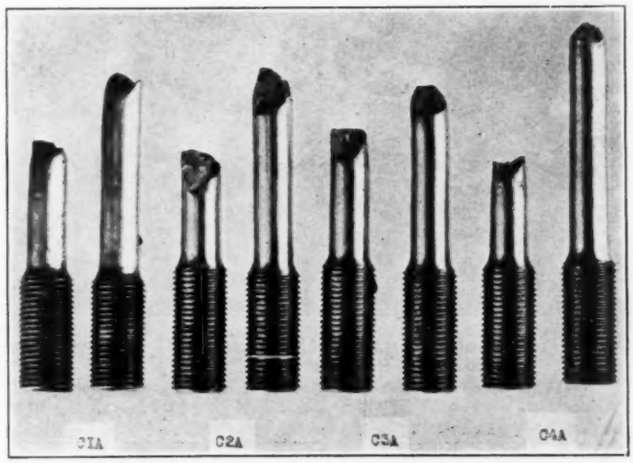


FIG. 18 SHOWING A FEW OF THE BROKEN TENSILE SAMPLES TAKEN FROM THE WELD METAL IN THE MANNER SHOWN BY THE CIRCLES IN FIG. 6
(The ultimate tensile strengths of these samples were: C-1-A, 65,300; C-2-A 71,100; C-3-A, 55,200; C-4-A, 61,200.)

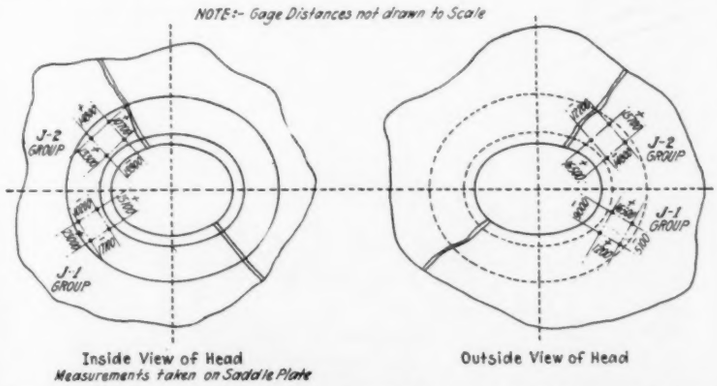

NOTE:- Gage Distances not drawn to Scale
J-2 GROUP
J-1 GROUP
Inside View of Head
Measurements taken on Saddle Plate
Outside View of Head

FIG. 19 SKETCH OF INTERIOR AND EXTERIOR VIEWS AT THE MANHOLE FLANGE, SHOWING THE POSITION AND MAGNITUDE OF THE STRESSES DESCRIBED IN TABLE 2

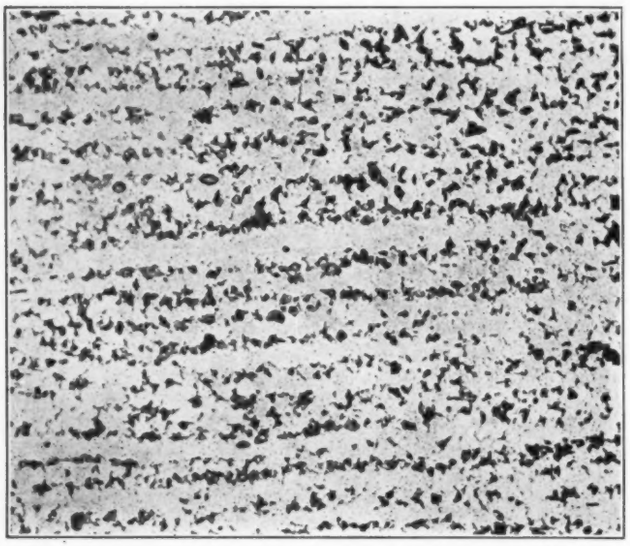


FIG. 20 TAKEN FROM SAMPLE "A-1" IN POSITION SHOWN IN FIG. 16. ×100
(Taken from head flange parallel to the tank axis.)

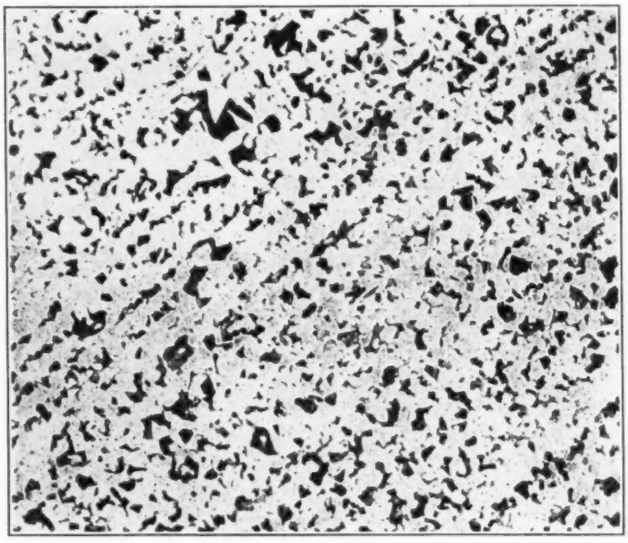


FIG. 21 TAKEN FROM SAMPLE "B-4" SHOWN IN FIG. 16. ×100
(This is the same as Fig. 20 but at right angles to "A-1" as shown in Fig. 5.)

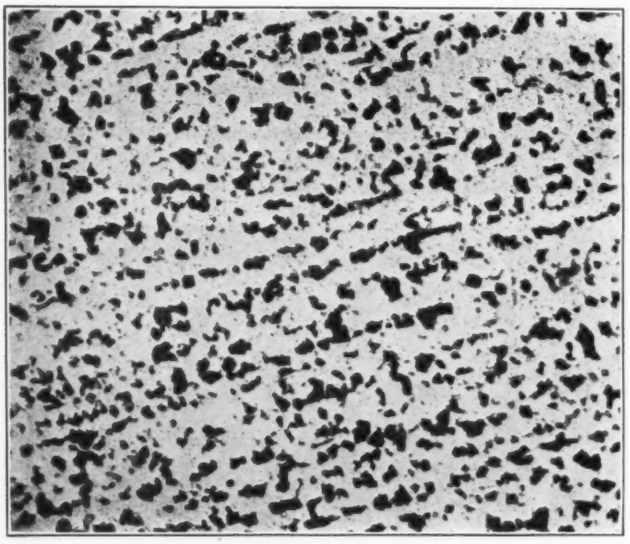


FIG. 22 TAKEN FROM SAMPLE "E-1" SHOWN IN FIG. 17 WITH THE POSITION IN THE TANK HEAD SHOWN IN FIG. 5. ×100
(This position was half-way between the knuckle and manhole.)

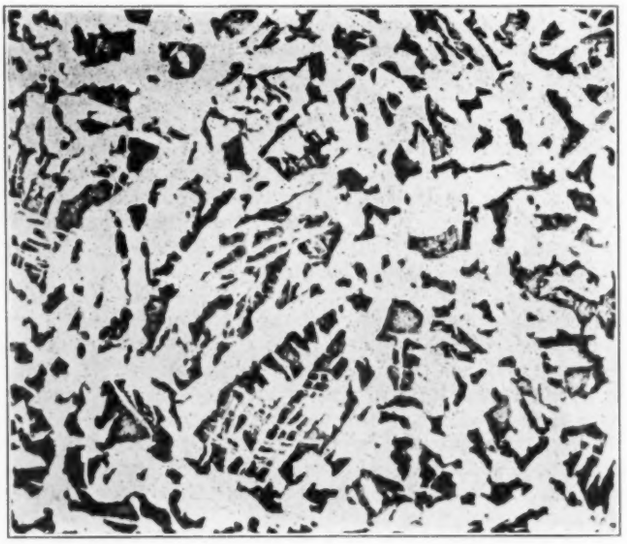


FIG. 23 TAKEN FROM SAMPLE "C-2-A" SHOWN IN FIG. 16 WHICH HAD THE POSITION SHOWN IN FIG. 5, THAT IS, TAKEN FROM THE BODY OF THE WELD METAL WITH THE AXIS OF THE TENSILE SPECIMEN LYING ALONG THE AXIS OF THE VEE. ×100
(This metal is coarse and typical of weld-deposited metal.)

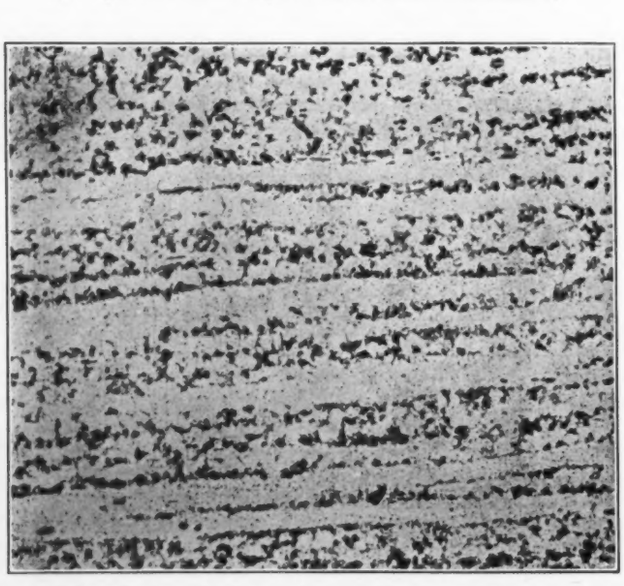


FIG. 24 TAKEN FROM "D-1" IN THE DIRECTION SHOWN BY THE LIGHT LINE IN FIG. 17. × 100
(The general position of the tensile sample is shown in Fig. 5 and is as close to the edge of the manhole as possible.)

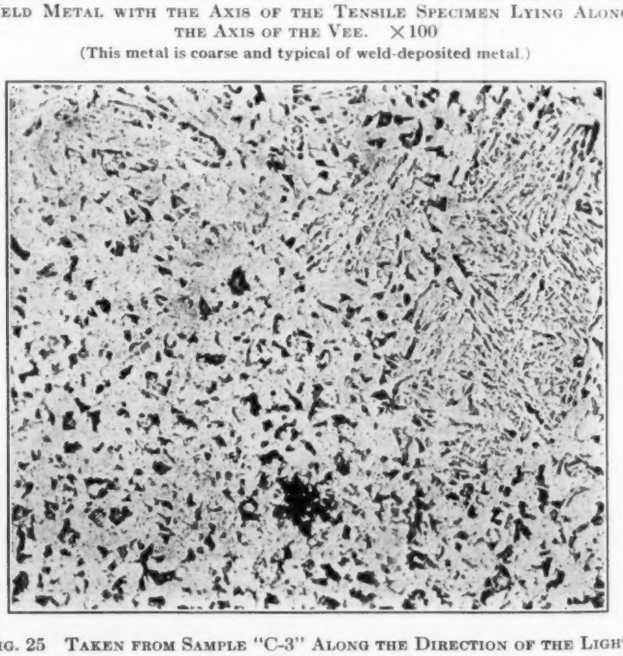


FIG. 25 TAKEN FROM SAMPLE "C-3" ALONG THE DIRECTION OF THE LIGHT LINE IN FIG. 16. ×100
(This tensile sample was taken from the tank head as close to the weld metal as possible, the exact position being similar to the inscribed circle in Fig. 6. The structure has become slightly coarser by the welding heat.)

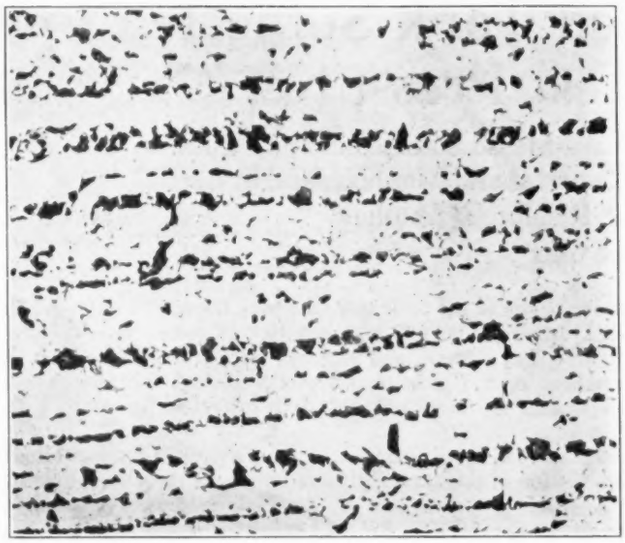


FIG. 26 TAKEN FROM "F-1" ALONG THE LIGHT LINE SHOWN IN FIG. 17. ×100

(This sample was taken close to the edge of the manhole flange as shown by the detailed sketch in Fig. 5. This is a highly banded structure and seems to contain less carbon than the tank-head material.)

CONCLUSIONS

1 The weld metal (nickel steel), shows ample strength and other physical properties.

2 The base metal next the weld was not injured by the heat of welding.

3 There was no significant difference in the physical properties of the metal in different parts of the head.

4 The welds were of good quality, and the fusion and penetration were satisfactory from a production standpoint.

5 There is no evidence that the 1000 lb. test pressure to which the tank was subjected affected the welds in any way.

Stelliting: A New Welding Process

BY A. V. HARRIS,[1] NEW YORK, N. Y.

STELLITE, which is an alloy composed of cobalt, chromium, and tungsten, is truly a unique metal. Its hardness is inherent, so it requires no tempering. After it has been cast in a form, stellite can be reduced only by grinding. Because of its inherent hardness, it cannot be machined or filled. It can be brought repeatedly to very near its melting point without losing this hardness. Subsequent cooling does not affect it. One of its highly desirable characteristics is the fact that it will resist wear and abrasion to a high degree. Stellite is highly resistant to the actions of practically all commercial and industrial acids. It is non-magnetic. The light reflecting power of the highly polished surface of stellite is only a little less than that of silver. It retains its polish under very severe conditions and the surface can be scratched only with difficulty.

A welder will become aware of one of stellite's most remarkable characteristics if he melts it under an oxyacetylene blowpipe. He will be able to apply it to any grade of steel, including carbon and alloy steels, and practically any of cast iron and, without heat treatment, have a surface which still retains the original properties of stellite. Copper can also be stellited.

"Stelliting," as the process is called, is neither welding nor brazing in the ordinary sense of the words. Stelliting calls for a blowpipe flame which contains a fairly large excess of acetylene to lower the flame heat and to exclude as much atmospheric oxygen as possible. The surface of the base metal to which the stellite is to be applied is brought up to such a heat that it just begins to sweat and assume an oily appearance. The lightest possible penetration into the parent metal is most desirable since this eliminates the possibility of an undesirable alloy being formed with the stellite.

At this point the stellite is melted from the welding rod and allowed to flow on to the base metal with as little agitation as possible. Examination of a stellite weld made in this manner shows that practically no penetration into or alloying with the base metal has occurred, and that the pores of the metal have not opened up and taken hold. The action of stellite flowing on to the steel is similar to that of solder flowing from an iron on to an already tinned surface.

Stellite can be welded with the electric carbon- or metallic-arc process, but the metal resulting from an oxyacetylene weld is cleaner, less porous, and unalloyed.

Numerous manufacturing plants have press jobs in which they are forced to use a metal which is as highly resistant to heat as possible, especially those involving the hot forming of sheet metal and the hot trimming of forgings. In hot forming sheet the ordinary highly tempered die of carbon or alloy steel must resist heat as well as abrasion. In very short time the heat of the forming operation will draw the temper to a point where the metal has begun to soften. When this occurs, it is necessary to anneal the die and remachine or grind and temper again; this procedure being carried through until the die is worn out and scrapped. Then it is necessary to make new dies.

Stellite is very desirable in applications to hot-forming and hot-trimming dies. A die of machine steel or carbon steel is made up in the usual manner, and the wearing surface is left approximately $^3/_{16}$ in. under size to allow for stelliting. After such a die has been stellited and ground to size, it will stand up indefinitely. For instance, in the making of automobile crankshafts which are forged to a very close limit, a flash is left on the forging. It is necessary to trim off this flash while the metal is still hot. Various steels and alloys have been employed in the making of trimming dies for this operation. These sometimes trim as many as 2000 pieces before they need reworking; still they are inefficient as compared to a stellited die. It is necessary only to stellite the edge of a trimming die. When this is properly done, the die will stand up under as many as ten and twelve thousand operations before requiring reworking. It is then necessary only to return the die to be re-stellited and ground, no tempering being needed.

Other resistance-to-heat applications are in the formation of dies for automobile spring clips, railroad anchors and numerous other fairly heavy steel sections which require hot forming or shaping.

Metal parts of portland-cement pulverizing, grinding, crushing, and conveying machinery, which are worn out in a very short time through abrasion or wear, acquire a great increase in life when stellited. A screw conveyor of the conventional type stellited on the periphery is now outlasting heat-treated carbon steels six to one. A stellite surface $^1/_8$ in. thick on a gudgeon as used in the cement plant will give the part a life three times as long as $^1/_2$ in. of steel. Blades of exhaust-heat fans such as are used in cement and various other industrial plants are cut down in a comparatively short time. By merely stelliting their worn surfaces, a welder increases their life by four. Hot drag-chain supports, conveyor buckets and cams, steam-shovel dipper teeth and roll-mill plows are profitably treated in the same way. Stelliting is used for homogenizing Diesel-engine equipment, for chemical compressors, and for a great variety of other chemical equipment. Stellite flowed on to steel or cast iron has the same properties as the original cast metal, the heat of the welding flame at no time robbing it of any of its properties.

In the manufacture of dry cells or dry radio batteries a number of dies and machine parts come in contact with active chemical compounds which tend to corrode and destroy the metals used. Increase in life imparted by stellite is the result of its ability to resist this corrosion as well as abrasion. The majority of the stellited parts for this use are as a unit.

In the transmission of pictures by radio at the present time stellite reflectors and mirrors are being used extensively. These are far superior to anything else because of the facts that they have a high and lasting polish and reflecting power, are not affected by atmospheric conditions, and do not scratch easily. Some large telescopes and microscopes are now equipped with stellite reflectors and mirrors for the same reasons.

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[1] Haynes Stellite Co.

Paper read before New York Section of the American Welding Society, October 19, 1926.

Stresses in a Large Welded Tank Subjected to Repeated High Test Pressures

Details of Test of 5-Ft. Tank 40 Ft. Long—Theoretical—Measured Stresses and Strains in Various Sections of the Shell, Around the Head Knuckles and Manhole, and in the Replaced Manhead with Ring-Reinforced Manhole

By T. W. GREENE,[1] NEW YORK, N. Y.

DURING the last three years, through the construction of many large welded tanks for one of the subsidiaries of Union Carbide and Carbon Corporation, an opportunity has been presented to develop and establish correct practices of design and methods of fabrication of large oxyacetylene-welded pressure vessels. In this development, strain-gage determinations of stress intensity have been employed to check design and application, and these investigations have made important contributions in improving the design. Recently a large high-pressure tank, 5 ft. in internal diameter by 40 ft. long, designed for a working pressure of 300 lb., was constructed. In proof testing this tank by subjecting it several times to a hydrostatic pressure of 1000 lb. per sq. in., the manhole head failed under the third application because of exceedingly high strains set up around the manhole.[2]

During the test of this tank, strain-gage measurements were taken at all important points, and this paper deals with an analysis of the stresses and strains measured in the shell and head, especially those around the head knuckles and manhole opening. The magnitude of the stresses and cause of failure are discussed with the view of presenting engineering data on the effect of head knuckles and manholes on stress distribution, and to indicate the necessity of giving more consideration to the proper design of heads and manholes if high-pressure tanks are to be constructed to have the same factor of safety throughout as in the shell.

Description of Tank

The tank tested was made of $1^1/_8$-in. shell plates, with the solid or plain head $1^1/_8$ in. and the manhole head $1^1/_4$ in. thick. The tank was constructed in accordance with the A.S.M.E. Unfired Pressure Vessel Code, except as noted below. The design fiber stress for the working pressure of 300 lb. was 8000 lb. per sq. in. in the shell and 9000 lb. in the head. The Code prescribes a lower fiber stress for the shell, but allows a higher fiber stress, 11,000 lb. per sq. in. in the head. A much larger knuckle radius than is customary was used, the outside corner radius being increased to 6 in. in order to reduce the stresses at the knuckle. The flange or skirt of the head was made 6 in. long to remove the head seam away from the knuckle, a point of high strain. As the manhole opening was known to be a point of weakness, the metal in the manhole saddle was increased about 25 per cent above that called for in the Unfired Pressure Vessel Code. The general design of the tank is shown in Fig. 1.[3]

Description of Test

In testing welded tanks, our procedure is to test to three times the working pressure as prescribed in the Unfired Pressure Vessel Code. This would require a hydrostatic test pressure of 900 lb. The tank was tested to 1000 lb., as it was decided to test according to the Code on the basis of 9000 lb. per sq. in. working fiber stress to see if this figure could be used in future designs. This gave a maximum test fiber stress of approximately 27,000 lb. per sq. in.

The test and strain measurements were made as follows:

The tank was first subjected to a hydrostatic pressure of 1000 lb. per sq. in. Strain-gage measurements were taken at all important points in the tank at 0 (the tank filled with water for the initial readings), 300, 600, 900, and 1000 lb. per sq. in. The pressure was then released and readings were taken to measure the permanent sets. These measurements showed the strains were high around the head knuckle, and extremely so around the manhole.

The tank was tested again to measure the stresses developed under reapplication of pressures and to determine if there would be any increase in the permanent set, especially around the manhole. The strains were measured in the second test at 300, 600, and 1000 lb. per sq. in. pressure and after the pressure was released. This second test showed no evidence of distortion except in the metal around the manhole, where there was an increase in permanent set.

A third test with strain measurements was made to see if the limit of yielding in the manhole head had been reached, as the safety of the tank was questioned, the intention being to carry the test to destruction unless it showed no further evidence of permanent set on the third test. At 930 lb. per sq. in. the head broke diagonally through the manhole. After the failure, readings were taken at all the gage points, which showed the permanent deformation around the manhole had materially increased, but that elsewhere throughout the tank the metal was not permanently strained or injured.

Another head employing a new design of manhole reinforcing ring was welded to the tank and the test continued. The stress measurements of this test showed that the stresses in the shell and plain head corresponded with those measured in the second and third tests, and that there was no further yielding or increase in permanent set. The tank was considered perfectly safe and subsequently put into operation.

The strain-gage measurements were made with 2-in. and 8-in. Berry strain gages. For taking the measurements, small holes were drilled with a No. 56 drill 2 in. and 8 in. apart at various points on the tank. Sufficient check readings were taken to insure an accuracy of 1500 lb. per sq. in. for the 2-in. and less than 1000 lb. per sq. in. stress for the 8-in. gage line.

Stresses and Strains in Tank Shell—Theoretical Consideration

The shell of a tank, according to the common approximate theory for thin cylinders under internal pressure, is subjected to three kinds of stresses: one, transverse or hoop tension, tending to cause rupture along an element of the cylinder; another, longitudinal, tending to cause rupture circumferentially; and a third, radial, due to the difference of internal and external pressures. The radial stresses are usually considered negligible since generally the pressure is relatively small.

The transverse and longitudinal stresses in the shell are found from the common design formulas

$$S_T = \frac{PD}{2t} \text{ and } S_L = \frac{PD}{4t}$$

where S_T and S_L are transverse and longitudinal stress, respectively, P the pressure, D the diameter, and t the thickness of the shell. These formulas give 8000 lb. per sq. in. for the transverse and 4000 lb. per sq. in. for the longitudinal stress for the tank tested under the working pressure of 300 lb. per sq. in.

The hoop stress is twice the longitudinal, but this ratio does not exist between the strains because the strain in any one direction in a material under two or more principal stresses is affected by lateral contraction from the stresses in the other directions. The

[1] Linde Air Products Company.

[2] This head failure is described by S. W. Miller in The Design of Dished Heads of Pressure Vessels in Mechanical Engineering, Aug., 1926.

[3] For detail of design and construction, see paper by H. E. Rockefeller on Oxyacetylene-Welded Construction of a Large High-Pressure Storage Tank, which will appear in the March issue.

Presented at a joint meeting of the Metropolitan Section and Machine Shop Practice Division of the A.S.M.E. with the New York Section of the American Welding Society, New York, January 4, 1927.

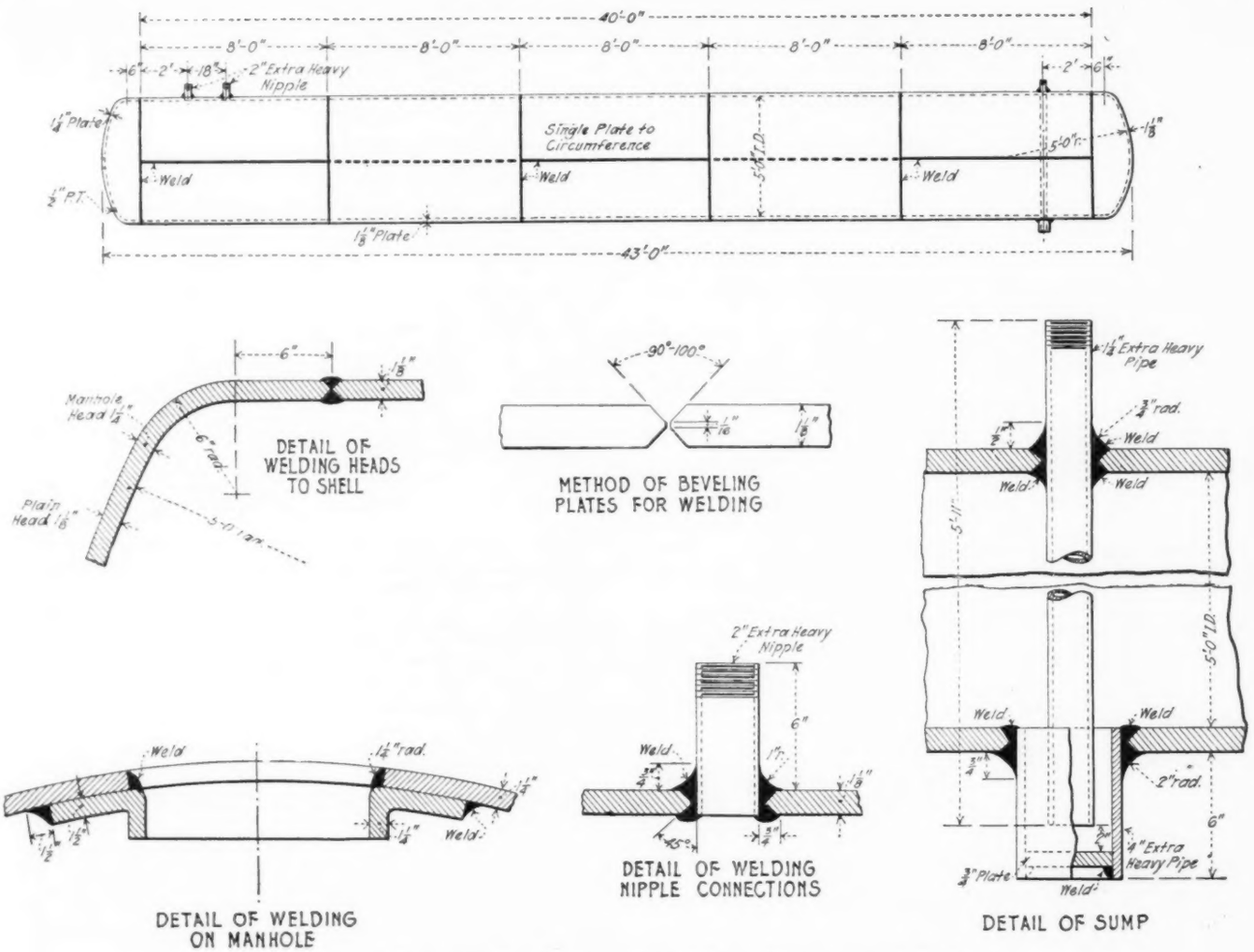


FIG. 1 GENERAL DESIGN OF HIGH-PRESSURE TANK 5 FT. IN DIAMETER BY 40 FT. LONG

relationship between the principal strains and principal stresses may be found from the following equations:

$$e_T = \frac{S_T}{E} - \frac{S_L + S_R}{ME}$$

$$e_L = \frac{S_L}{E} - \frac{S_R + S_T}{ME}$$

$$e_R = \frac{S_R}{E} - \frac{S_T + S_L}{ME}$$

where e_T, e_L, e_R = transverse, longitudinal, and radial strains respectively

S_T, S_L, S_R = transverse, longitudinal, and radial stresses, respectively

E = Young's modulus (29,000,000 lb. per sq. in. for steel)

$1/M$ = Poisson's ratio, or factor of lateral contraction.

Assuming S_R is zero and $1/M = 1/3$, these equations may be solved for the stresses in terms of the strains, giving

$$S_T = 3/8E(3e_T + e_L)$$

$$S_L = 3/8E(3e_L + e_T)$$

These equations show that the transverse or hoop strain in the shell of a tank is five times the longitudinal strain, and that their values are $5/8$ and $1/3$ of the strains that would exist if the transverse or longitudinal stress were acting alone and independently as a one-dimensional stress. These formulas for determining the common design stresses from the actual strains will be designated in the paper as the "two-dimensional formulas."

Clavarino's formula, which is theoretically correct for hollow cylinders with closed ends, gives the stresses corresponding to the actual deformation. This formula, which is based upon considera-

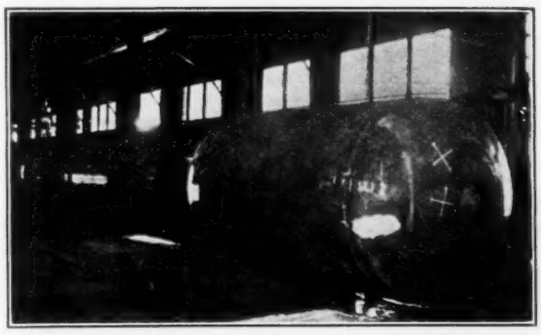


FIG. 2 GENERAL VIEW OF TANK OF FIG. 1, SHOWING LOCATION OF A GROUP OF 8-IN. GAGE LINES ON SIDE OF SHELL AND SPECIAL GROUP OF 2-IN. GAGE LINES AROUND KNUCKLE OF PLAIN HEAD

(Note whitewash spots on tanks to show up scaling on yielding or Luders lines. No distress was observed at seams.)

tion of three-dimensional stresses, radial compression, transverse and longitudinal tension, and the effect of coefficient of lateral contraction or Poisson's ratio, gives for any point in the shell when the value of Poisson's ratio is taken as $1/3$,[4]

$$T_c = \left[R_1^2 P_1 - R_2^2 P_2 + \frac{4R_1^2 R_2^2}{X^2} (P_1 - P_2) \right] \div 3(R_2^2 - R_1^2)$$

[4] Merriman's Mechanics of Materials, art. 152, 11th Ed.

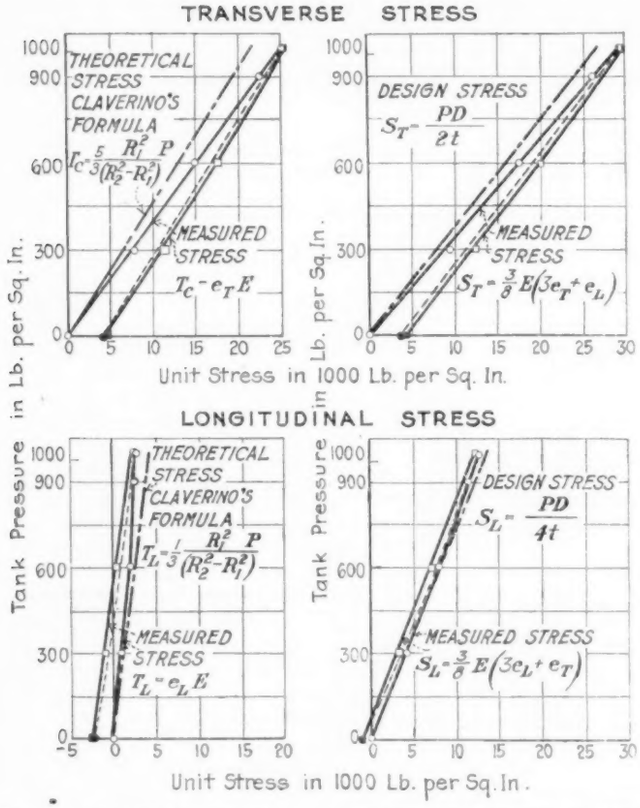


FIG. 3 AVERAGE LONGITUDINAL AND TRANSVERSE STRESSES IN SHELL OF TANK—FIRST AND SECOND TESTS

where T_c = transverse or cylindrical hoop stress at any point corresponding to actual deformation
X = distance of any point in the cylinder from the central axis
R_1 = inside radius
R_2 = outside radius
P_1 = internal pressure
P_2 = external pressure.

For the outside pressure P_2 taken as zero, the stress at the inner surface $x = R_1$ is

$$T_c = {}^1/_3 P \left(\frac{R_1^2 + 4R_2^2}{R_2^2 - R_1^2} \right)$$

For stress at the outer surface $x = R_2$

$$T_c = {}^5/_3 P \left(\frac{R^2}{R_1^2 - R_1^2} \right)$$

It can be shown that the longitudinal stress corresponding to the actual deformation is

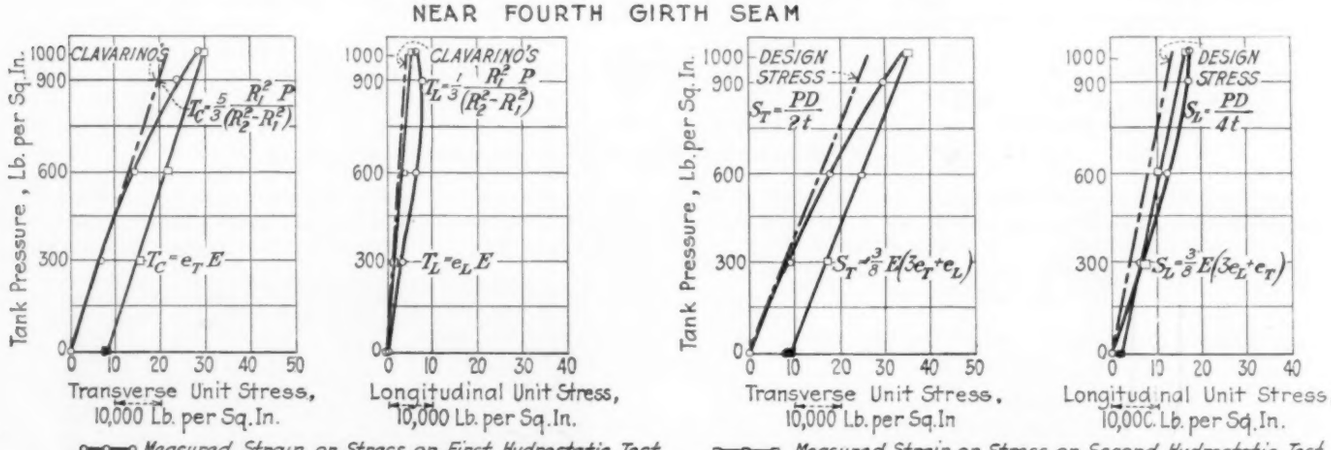
$$T_L = {}^1/_3 P \left(\frac{R_1^2}{R_2^2 - R_1^2} \right)$$

These formulas show that the transverse or hoop stress at the outer surface is five times the longitudinal stress. The transverse stress at the inner surface for the tank tested is about 6 per cent higher than at the outer surface, being 6950 and 6550 lb. per sq. in., respectively, at 300 lb. pressure.

These stresses, since they correspond to the actual deformation, should agree theoretically with the eE stress measured with the strain gage, e being the actual strain measured and E Young's modulus.

MEASURED STRESSES IN THE ROUND SECTION OF SHELL

The stresses in the shell were measured on a group of 8-in. gage


NEAR FOURTH GIRTH SEAM
Tank Pressure, Lb. per Sq. In.
CLAVERINO'S
$T_c = \frac{5}{3}\frac{R_1^2 P}{(R_2^2 - R_1^2)}$
$T_c = e_T E$
Transverse Unit Stress, 10,000 Lb. per Sq. In.
CLAVERINO'S
$T_L = \frac{1}{3}\frac{R_1^2 P}{(R_2^2 - R_1^2)}$
$T_L = e_L E$
Longitudinal Unit Stress, 10,000 Lb. per Sq. In.
DESIGN STRESS
$S_T = \frac{PD}{2t}$
$S_T = \frac{3}{8}E(3e_T + e_L)$
Transverse Unit Stress, 10,000 Lb. per Sq. In
DESIGN STRESS
$S_L = \frac{PD}{4t}$
$S_L = \frac{3}{8}E(3e_L + e_T)$
Longitudinal Unit Stress, 10,000 Lb. per Sq. In.
Measured Strain or Stress on First Hydrostatic Test
Permanent Set after First Hydrostatic Test
Measured Strain or Stress on Second Hydrostatic Test
Permanent Set after Second Hydrostatic Test

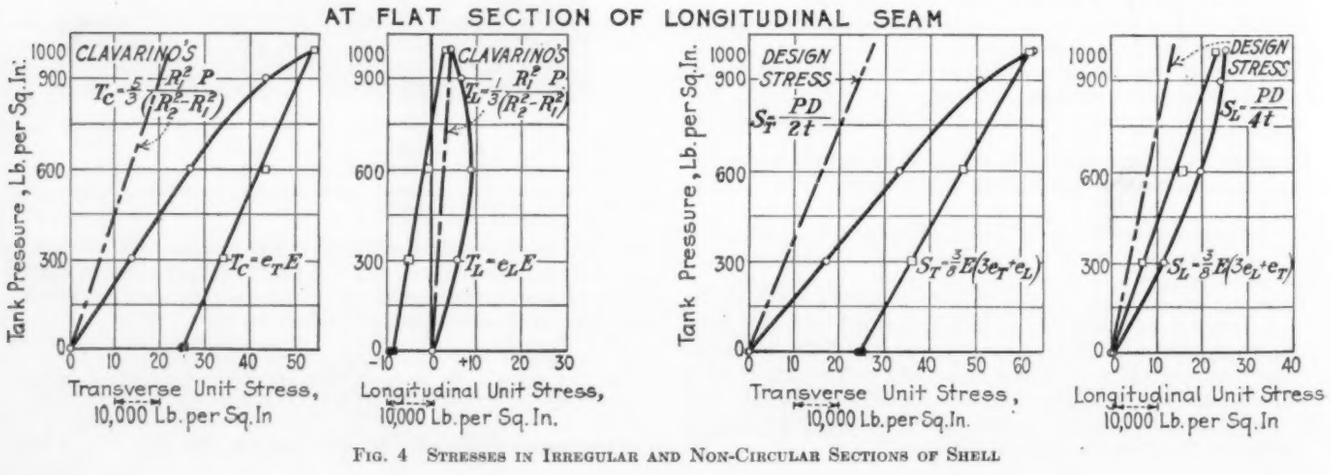

AT FLAT SECTION OF LONGITUDINAL SEAM
Tank Pressure, Lb. per Sq. In.
CLAVERINO'S
$T_c = \frac{5}{3}\frac{R_1^2 P}{(R_2^2 - R_1^2)}$
$T_c = e_T E$
Transverse Unit Stress, 10,000 Lb. per Sq. In
CLAVERINO'S
$T_L = \frac{1}{3}\frac{R_1^2 P}{(R_2^2 - R_1^2)}$
$T_L = e_L E$
Longitudinal Unit Stress, 10,000 Lb. per Sq. In.
DESIGN STRESS
$S_T = \frac{PD}{2t}$
$S_T = \frac{3}{8}E(3e_T + e_L)$
Transverse Unit Stress, 10,000 Lb. per Sq. In.
DESIGN STRESS
$S_L = \frac{PD}{4t}$
$S_L = \frac{3}{8}E(3e_L + e_T)$
Longitudinal Unit Stress 10,000 Lb. per Sq. In

FIG. 4 STRESSES IN IRREGULAR AND NON-CIRCULAR SECTIONS OF SHELL

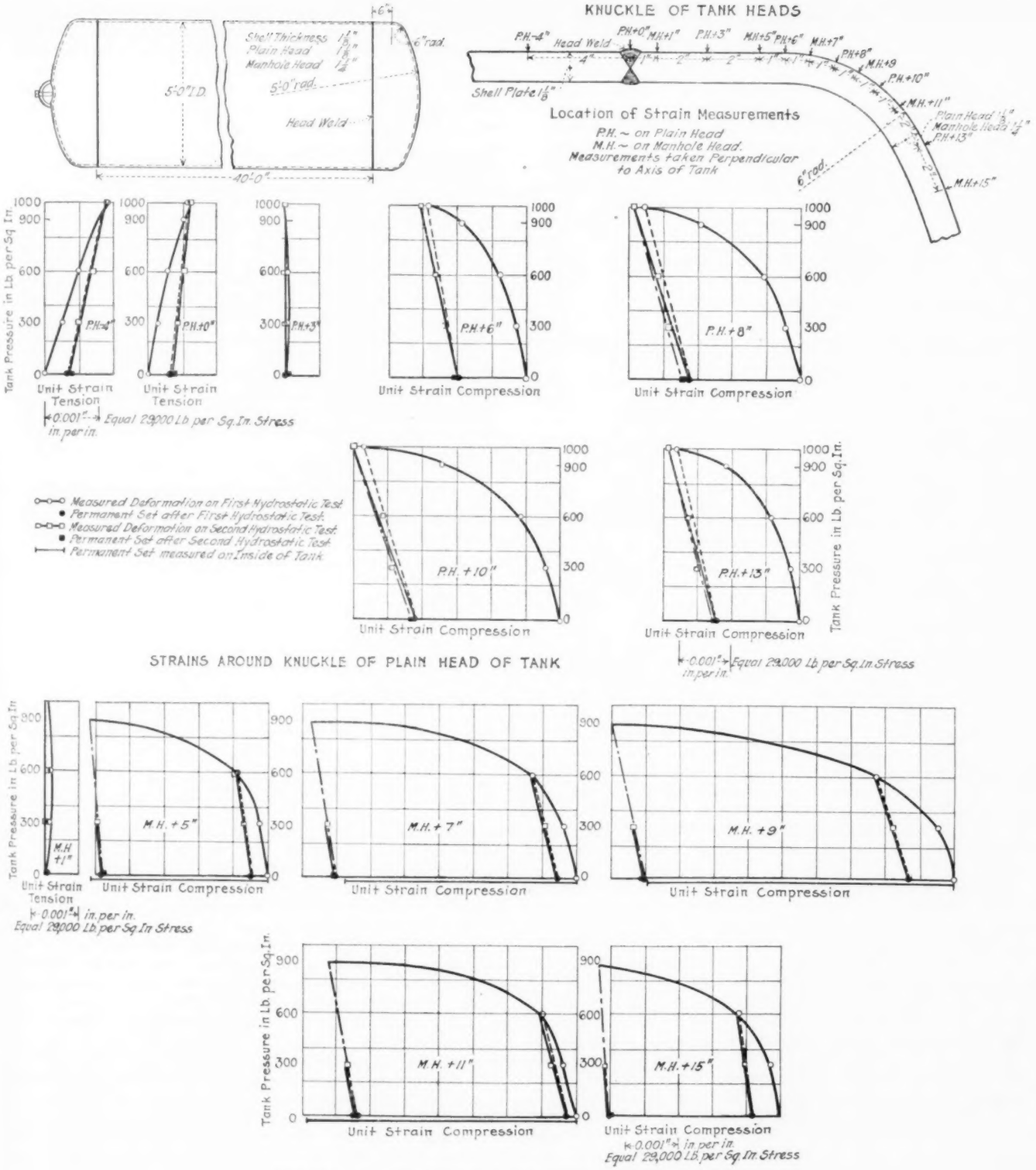

KNUCKLE OF TANK HEADS
Shell Thickness 1 1/8"
Plain Head 1 1/8"
Manhole Head 1 1/4"
5'-0" I.D.
5'-0" rad.
6" rad.
Head Weld
40'-0"
P.H.-4" P.H.+0" M.H.+1" P.H.+3" M.H.+5" P.H.+6" M.H.+7" P.H.+8" M.H.+9" P.H.+10" M.H.+11" P.H.+13" M.H.+15"
Shell Plate 1 1/8"
Plain Head 1 1/8"
Manhole Heads 1 1/4"
Location of Strain Measurements
P.H. ~ on Plain Head
M.H. ~ on Manhole Head.
Measurements taken Perpendicular to Axis of Tank
Tank Pressure in Lb. per Sq. In.
Unit Strain Tension
Unit Strain Compression
0.001" in per in. Equal 29,000 Lb per Sq. In. Stress
Measured Deformation on First Hydrostatic Test
Permanent Set after First Hydrostatic Test
Measured Deformation on Second Hydrostatic Test
Permanent Set after Second Hydrostatic Test
Permanent Set measured on Inside of Tank
STRAINS AROUND KNUCKLE OF PLAIN HEAD OF TANK
STRAINS AROUND KNUCKLE OF MANHOLE HEAD OF TANK

FIG. 5 STRAINS AROUND KNUCKLES OF PLAIN AND MANHOLE HEADS OF TANK

lines, three longitudinal, three transverse, spaced 4 in. apart. (See square group on side of tank in Fig. 2.) The average longitudinal and transverse stresses measured on this group for the first and second tests are given in Tables 1 and 2 and are shown plotted on Fig. 3. The measurements for the third and fourth tests agreed with the second with no increase in the permanent set, so are not given. In Table 1 the stresses are expressed in terms of the common design stress, computed by combining both the measured longitudinal and transverse strains in the two-dimensional formula. In Table 2 the measured stresses eE obtained by multiplying the measured strains in one direction by the modulus of elasticity are compared with Clavarino's formula.

These results show that the stresses measured in the second test agreed very closely with the theoretical. In the first test the agreement was not so close; moreover the metal was permanently deformed by the pressure. This is due to bending stresses superimposed on the straight tensile stresses. The shell plate at the point measured appeared to be round and concentric, but due to irregularities in rolling and other causes, it is probably impossible to obtain exact concentricity in a tank shell. The pressure tends

TABLE 1 STRESSES IN ROUND SECTION OF SHELL (TWO-DIMENSIONAL MEASURED STRESSES COMPARED WITH DESIGN STRESSES)

	First Hydrostatic Test					
	Transverse			Longitudinal		
Hydrostatic pressure	Design stress $S_T = PD/2t$ lb. per sq. in.	Measured strain e_T in. per in.	Measured stress $S_T = {}^3/_8E \times (3e_T + e_L)$ lb. per sq. in.	Design stress $S_L = PD/4t$ lb. per sq. in.	Measured strain e_L in. per in.	Measured stress $S_L = {}^3/_8E \times (3e_L + e_T)$ lb. per sq. in.
0	0	0	0	0	0	0
300	8,000	0.000275	9,400	4,000	0.000037	4,200
600	16,000	0.000512	17,500	8,000	0.000070	7,900
900	24,000	0.000775	26,200	12,000	0.000085	11,200
1000	26,600	0.000822	29,300	13,300	0.000097	12,700
0	0	+0.000140*	...	0	−0.000075*	...
	Second Hydrostatic Test					
0	0	0	0	0	0	0
300	8,000	0.000252	8,700	4,000	0.000045	4,200
600	16,000	0.000470	16,300	8,000	0.000088	8,000
1000	26,600	0.000740	25,900	13,300	0.000155	13,100
0	0	0	0	0	0	0

* Permanent set, + tension, − compression.

TABLE 2 STRESSES IN ROUND SECTION OF SHELL (MEASURED STRESSES eE COMPARED WITH CLAVARINO'S FORMULA)

	First Hydrostatic Test					
	Transverse			Longitudinal		
Hydrostatic pressure	Clavarino's $T_c = {}^1/_2P \times R_1^2/(R_2^2 - R_1^2)$ lb. per sq. in.	Measured strain e_T in. per in.	Measured stress $T_c = e_TE$ lb. per sq. in.	Clavarino's $T_L = {}^1/_2P \times \frac{R_1^2}{R_2^2 - R_1^2}$	Measured strain e_L in. per in.	Measured stress $T_L = e_LE$ lb. per sq. in.
0	0	0	0	0	0	0
300	6,550	0.000275	8,000	1300	0.000037	1100
600	13,100	0.000512	14,900	2600	0.000070	2000
900	19,650	0.000775	22,500	3900	0.000085	2500
1000	21,800	0.000822	25,300	4400	0.000097	2800
0	0	+0.000140*	...	0	−0.000075*	...
	Second Hydrostatic Test					
0	0	0	0	0	0	0
300	6,550	0.000252	7,300	1300	0.000045	1300
600	13,100	0.000470	13,600	2600	0.000088	2500
1000	21,800	0.000740	21,400	4400	0.000155	4500
0	0	0	0	0	0	0

* Permanent set, + tension, − compression.

to round out these irregularities and force the shell to a true circle, thus setting up local bending stresses. The combined stress under the high pressure may cause the elastic limit of the material to be exceeded and the metal permanently deformed to iron out these irregularities.

The measurements show that this occurred. The shell of the tank at the point measured was permanently deformed by the pressure to iron out the invisible irregularities that caused the additional bending stresses on the first test. After the first high-test pressure had forced the plate to a true circle, the stresses were normal as shown by the close agreement with theory in the second test.

The results show the actual strain stresses eE agree with the stresses computed by Clavarino's formula, as would be expected since theoretically Clavarino's formula give the stresses corresponding to the actual deformation. In Table 2 it is seen that the strain stress of 25,300 lb. per sq. in. as obtained from the actual deformation for comparison with Clavarino's formula produced permanent deformation, although the elastic limit of the material is well above this figure. In Table 1, using the two-dimensional formula in calculating the stress from the measured strains, 29,300 lb. per sq. in. was obtained. This approximates the elastic limit of the material, and the small permanent set is expected. Thus it appears from the results that the elastic limit of steel subjected to stress in two or more directions is reached at a lower unit strain than under a one-dimensional stress. Consequently a lower elastic-limit stress value than that determined in a simple tensile test should be considered where stresses are based on actual deformation or strain. In using Clavarino's formula it appears this should be taken into consideration, otherwise it may give results that err on the side of danger.

Measured Stresses in Slightly Irregular and Non-Circular Section of Shell

To determine the effect irregularities in the shell have on the stress distribution, strain measurements were taken at two points selected where the shell was visibly eccentric. One group of strain readings was taken near the fourth girth seam where one course was slightly offset in reference to the adjacent one, and a second group across a longitudinal seam where a section of the shell was flat. The results of these measurements are shown in Fig. 4. Both the measured strain stress eE for comparison with Clavarino's formula and two-dimensional measured stress for comparison with common design formulas are given.

These curves show that bending stresses were developed by the pressure tending to iron out the irregularities, which combined with the straight tensile stresses caused the metal to be strained above the elastic limit and permanently deformed. At the fourth girth seam the first hydrostatic test apparently removed the effect of the irregularity, as the stresses developed on the second and subsequent tests checked with theory (compare slope of curves of second test with the theoretical stress line).

At the flat longitudinal seam the stresses developed in the second test were very much less than in the first, but still somewhat greater than the theoretical. The metal was not strained above the elastic limit on reapplication of the same maximum pressure as the strains are proportional to the pressures. The elastic limit apparently was raised by the cold working in the first test. It appears that the pressure of 1000 lb. rounded out the flat spot an appreciable extent to minimize the effect of the irregularity, but not sufficiently to reduce the stresses to normal on subsequent applications of pressure. These results seem to indicate that the high test pressure improved the condition of the tank shell.

Stresses Around Head Knuckles

The stresses around the knuckle of a tank are generally known

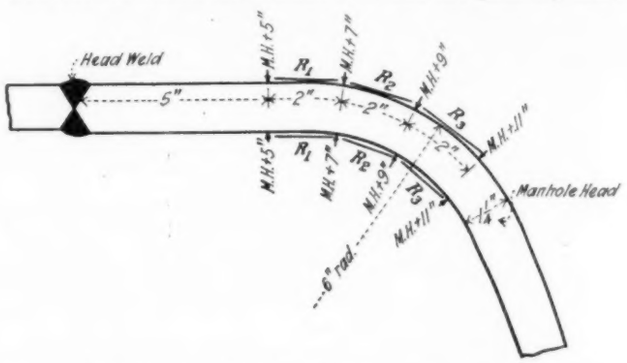


Fig. 6 Location of 2-In. Gage Lines Around Head Knuckle

to be high. Heads with a large radius of dish and small knuckle radius do not act as sections of spheres except at relatively low pressures. Under high pressures, such heads appear to act more as a dished plate supported at the rim. At the knuckle where there is an abrupt change in curvature and directional changes in the acting forces, high bending stresses are set up. The head under the internal pressure tends to protrude at the center of the tank and flatten or contract at the knuckle. Consequently very high strains are imposed in and near the knuckle, and if the elastic limit of the material be exceeded the head will take on a new shape, tending to assume that of an ellipsoid of revolution. This marked deformation of the knuckle and adjacent portions of the shell and head has been noted many times in tanks tested to destruction.

To measure the knuckle stresses, 2-in. gage lines were established approximately two inches apart on the knuckle and adjacent sections of the shell and head. (These groups of strain-gage lines can be seen in Fig. 2.) The results of these strain measurements are shown in Fig. 5, the sketch in the figure showing the exact location of the strain measurements which are plotted in the curves. The strains around the knuckle of the manhole head are those measured on the replaced head, no measurements being made at this point on the head that failed. Readings were not taken at 900 lb. in testing this head, but the curves are extrapolated to this pressure from the measurements of the permanent sets. The permanent sets measured at corresponding positions on the inside of the tank are shown below these curves.

In all the curves the unit strains or measured deformations in inches per inch are plotted as abscissas. These unit strains can be evaluated in terms of stress below the elastic limit by multiplying by the modulus of elasticity; thus, a unit strain of 0.001 in. per in. equals a stress of 29,000 lb. per sq. in.

These results show that the strains in a direction at right angles to the axis of the tank, that is, the hoop strains, change from tension on both sides of the knuckle to compression at the knuckle, the compression strains reaching a maximum at the center of the knuckle curvature. Fig. 5 shows that this compression extends for more than 6 in. both ways from the knuckle. At operating pressure the strains are not high, but when the pressure is increased to two or three times the design load they become excessive, exceeding the elastic limit.

These curves in Fig. 5 show that after the metal is once deformed by a given internal pressure, the stresses in future will be within the elastic limit and no further permanent set will occur as long as that given pressure is not exceeded. If the pressure is increased, the deformation will continue until the head is readjusted to the higher pressure.

Higher strains were developed around the knuckle of the manhead than in the plain head, even though the plate thickness was greater. The effect of the manhole opening in increasing the stress throughout the head is quite evident.

In analyzing the deformation which takes place at the knuckle, it would be expected that the hoop strain would be uniform throughout the plate thickness as there is no bending in this direction and the results show that the permanent sets are due to compression and are of the same magnitude inside and outside of the tank. In a radial direction, however, bending occurs as the knuckle flattens, so the radial strains should be higher on the inside. This is shown by the permanent sets measured around the knuckle given in Table 3. The radial permanent sets on the inside of the tank are very large and in tension, whereas on the outside they are relatively small and in some cases in compression, indicating bending.

FIG. 7 VIEW SHOWING LOCATION OF STRAIN-GAGE MEASUREMENT POINTS

TABLE 3 MEASURED PERMANENT SET ON OUTSIDE AND INSIDE OF TANK AROUND HEAD KNUCKLE AFTER TANK WAS TESTED TO 900 LB. (SEE FIG. 6)

	Permanent Set in Inches per Inch						
	Hoop (Perpendicular to axis of tank) at				Radial at		
	MH+5"	MH+7"	MH+9"	MH+11"	R_1	R_2	R_3
Outside...	C 0.0033	C 0.0049	C 0.0062	C 0.0044	T 0.0032	T 0.0011	C 0.0022
Inside....	C 0.0034	C 0.0045	C 0.0059	C 0.0050	T 0.0121	T 0.0136	T 0.0206

STRESSES AND STRAIN AROUND MANHOLE

The strains around the manhole were measured at both the long and short axes. Two-inch gage lines were established at the edge of the opening, one inch and two inches from the edge—see Fig. 7. The results of these measurements are shown in the curves in Fig. 8.

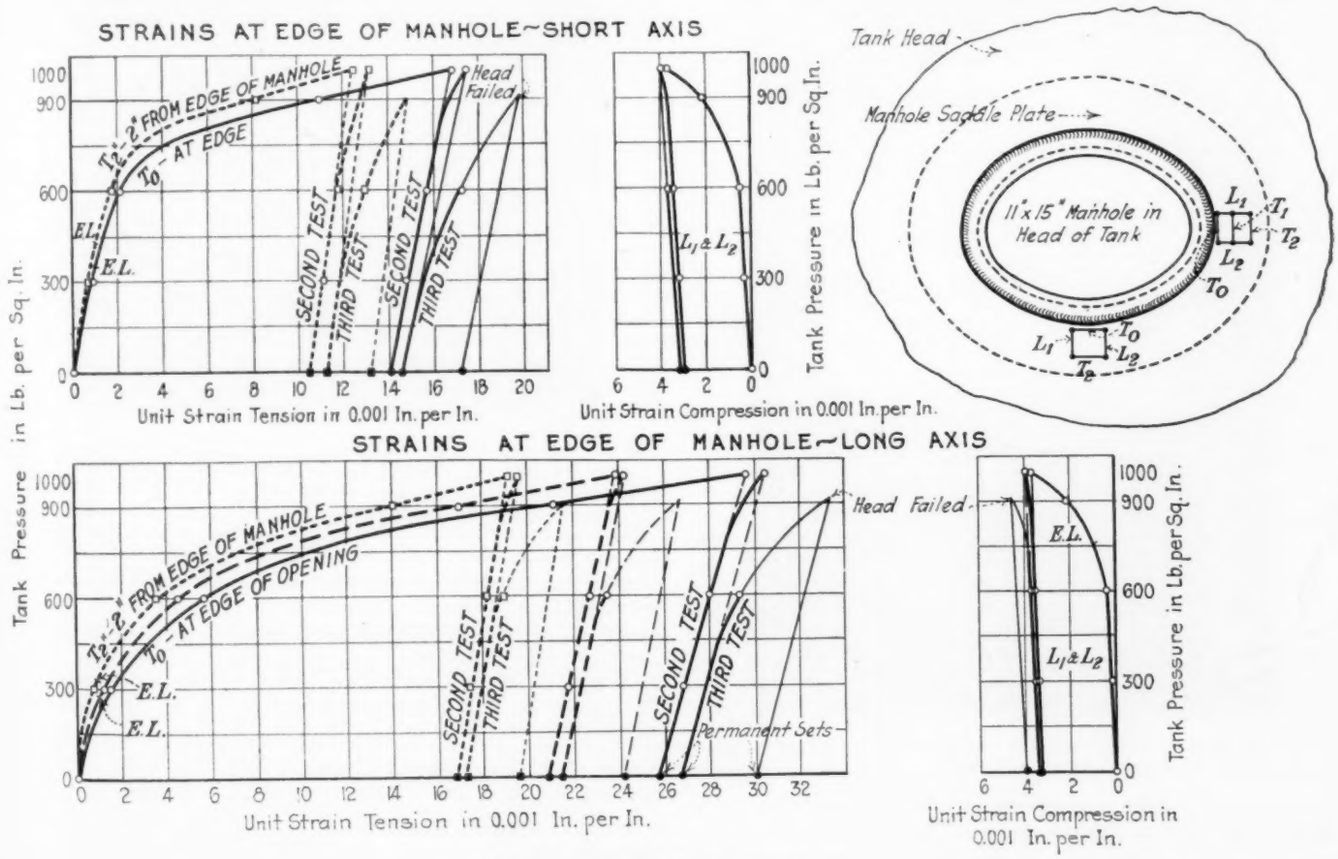

STRAINS AT EDGE OF MANHOLE—SHORT AXIS
Tank Pressure in Lb. per Sq. In.
1000
900
600
300
0
T2 - 2" FROM EDGE OF MANHOLE
T0 - AT EDGE
E.L.
SECOND TEST
THIRD TEST
Head Failed
0 2 4 6 8 10 12 14 16 18 20
Unit Strain Tension in 0.001 In. per In.
L1 & L2
6 4 2 0
Unit Strain Compression in 0.001 In. per In.
Tank Head
Manhole Saddle Plate
11"x15" Manhole in Head of Tank
L1
T1
T2
L2
T0
STRAINS AT EDGE OF MANHOLE—LONG AXIS
T2 - 2" FROM EDGE OF MANHOLE
T0 - AT EDGE OF OPENING
Permanent Sets
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Unit Strain Tension in 0.001 In. per In.
Unit Strain Compression in 0.001 In. per In.

FIG. 8 STRAINS AT EDGE OF MANHOLE
(Note indications of slip lines in left section of head.)

These curves show the strains measured on the first, second, and third tests with the permanent sets produced. No measurements were taken in the third test at 930 lb., the pressure at which the head failed, as it was intended to take readings at 1000 lb., but the curves are extrapolated to the pressure from measurements of permanent sets after failure.

TABLE 4 COMPARISON OF MAXIMUM STRESS AROUND MANHOLE WITH MEASURED STRESSES AT OTHER POINTS OF TANK

	Maximum stress measured near manhole	Ratio of Manhole Stress to Stress in shell plate		Stress around knuckle, plain head	
		Stress	Ratio	Stress	Ratio
At 300 lb. working pressure	44,000 lb. per sq. in.	8,000 lb. per sq. in.	5.5	−8700 lb. per sq. in.	5
At 600 lb. pressure	0.00559*	0.00051*	11	−0.00079*	7
At 900 lb. pressure	0.02110*	0.00077*	27	−0.00237*	9
At 1000 lb. pressure	0.02960	0.00087	34	−0.00393	7.5
Permanent set after 1000 lb	0.02575	0.00014	184	−0.00290	9

* Measured unit deformation or strain, inches per inch.
− Indicates compression hoop strains at knuckle.

The curves show that the strains around the manhole were extremely high. They were highest at the edge of the opening, but much less away from the edge, at two inches from the opening being a little over half that at the edge. But even at two inches away, they were greatly beyond the safety point.

These curves show one distinct feature about the behavior of the metal that the other strain curves in this paper do not show. On each successive application of the pressure there was further yielding of the metal around the manhole and an increase in the permanent set. The intensity of the forces acting around the opening was either so large or the metal was so overstrained that continued yielding occurred. It was inevitable that the manhole head should fail.

FIG. 9 LUDERS LINES AROUND KNUCKLES OF TANK AT THREE TIMES DESIGN PRESSURE

The magnitude of the strains around the manhole can be appreciated by comparing them with those measured on the shell. Table 4 gives the maximum strains around the opening and the ratio of these strains to measured stresses in other parts of the tank.

The exact reason for the strains being so extremely high around the manhole is not definitely determined. It is generally known that discontinuities cause very high stresses to be developed in the vicinity of the opening. Mathematical analysis, which has been proved experimentally by the work of Coker and others, has been developed to determine these stresses. It can be shown that around an opening in a flat plate sufficiently wide so that boundary influence may be neglected, the stress at any point in the transverse section through the hole when the plate is strained in one direction, is[5]

$$T_1 = \frac{T}{2}\left(2 + \frac{a^2}{X^2} + \frac{3a^4}{X^4}\right)$$

FIG. 10 SCALING AROUND MANHOLE UNDER PRESSURE SLIGHTLY IN EXCESS OF DESIGN PRESSURE, SHOWING EXCESSIVE STRAINS DEVELOPED AROUND OPENING

in which T_1 denotes the normal stress at any point, T the normal stress if no hole existed, a the radius of the hole, and X the distance of the point considered from the center of the hole. This equation shows that the maximum stress occurs at the edge of the opening and is three times the normal stress in the plate. The stress rapidly decreases from the edge.

In the case of an elliptical hole the maximum stress occurs at the edge at the ends of the major axis and may be found from the equation[6]

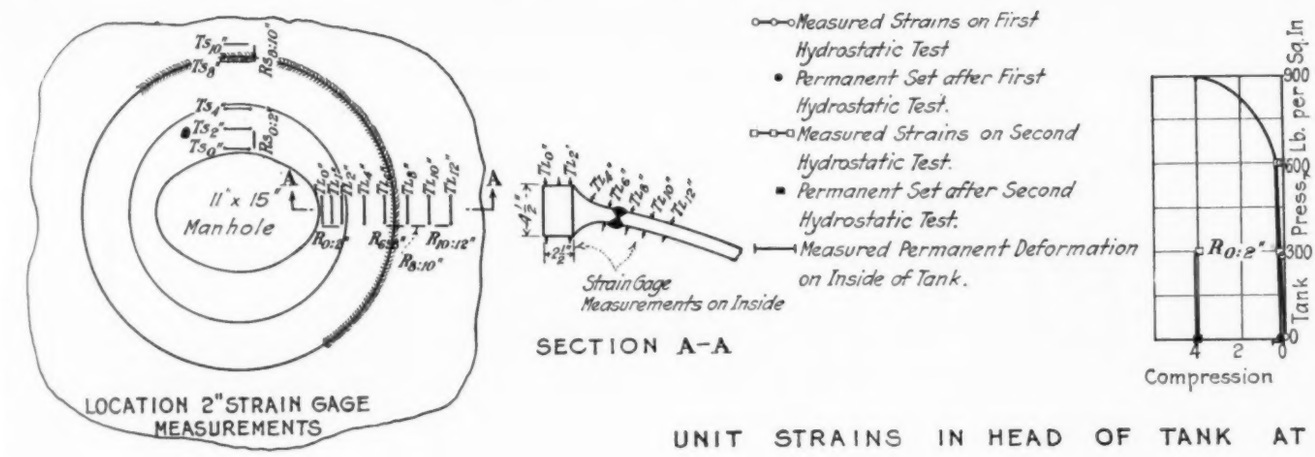
$$T_{max.} = T\left(1 + \frac{2a}{b}\right)$$

When the tension is uniform in all directions the same theory indicates that the stress at the edge of a circular hole is twice the normal stress, provided the plate is relatively large in comparison with the opening.

The strains measured around the manhole opening even with the reinforcement were much larger than twice the strains measured in the plain head. The stress concentration is no doubt largely

[5] The Distribution of Stress in Plates Having Discontinuities, by Suyehiro, *Engineering*, vol. 92 (1911).

[6] C. E. Inglis, *Engineering*, vol. 95 (1913), p. 415.


Measured Strains on First Hydrostatic Test
Permanent Set after First Hydrostatic Test.
Measured Strains on Second Hydrostatic Test.
Permanent Set after Second Hydrostatic Test.
Measured Permanent Deformation on Inside of Tank.
11" x 15" Manhole
LOCATION 2" STRAIN GAGE MEASUREMENTS
Strain Gage Measurements on Inside
SECTION A-A
Tank Press., Lb. per Sq. In.
Compression
UNIT STRAINS IN HEAD OF TANK AT

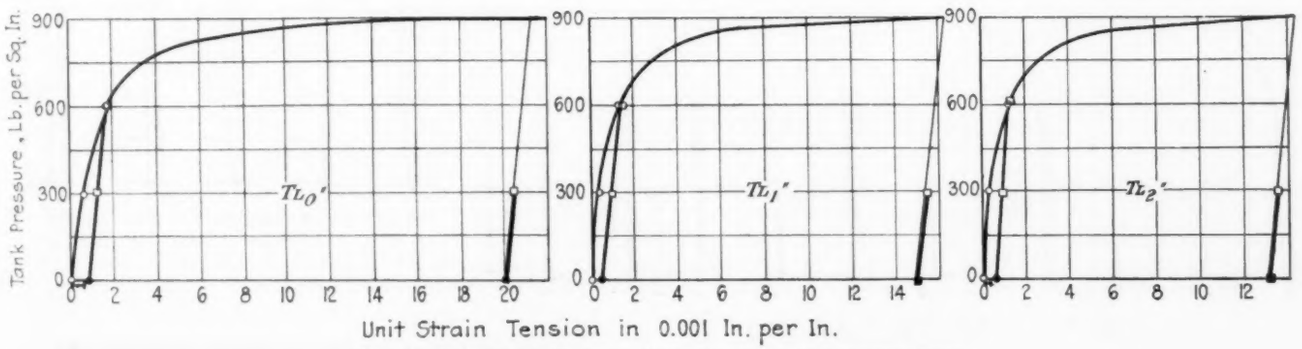


FIG. 11 RESULTS OF TEST OF MANHEAD WITH REINFORCING RING

due to the effect of the discontinuity of stress flow at the opening, but it is believed that bending strains are also imposed by the pressure on the manhole cover. These combined stresses concentrate around the opening and, at very low pressure, exceed the elastic limit, causing the metal to be highly deformed.

There is also the consideration that the usual formulas for head design add an arbitrary amount to the thickness to take care of the stresses in the knuckle, and another arbitrary amount to take care of the stresses around the manhole. These amounts have probably been sufficient for conditions governing where heads were comparatively thin, but with the thick heads the amounts added, which used to be from 25 to 50 per cent of the head thickness, may be less than 10 per cent. What effect increasing the thickness by a percentage would have is problematical, but even if enough strength could be obtained, much more metal would be needed than is required by good design, and the manufacturing difficulties would be increased very greatly.

STRESSES IN REPLACED MANHEAD WITH RING-REINFORCED MANHOLE

After the manhead failed in the test, a new design of manhead was developed. A machined slab $4^1/_2$ in. thick was used to give a heavy ring reinforcement around the opening. At the major axis this ring was $4^1/_2$ in. thick by $2^1/_2$ in. deep and was tapered down to the $1^1/_4$-in. head plate. At the minor axis the ring was about $4^1/_2$ in. deep. This was done for easy machining, as it had to be cut out of the solid slab of steel. This machined slab was welded in a new head, which was the same as the one that failed except for the manhole design.

The tank with the new head was tested first to 600 lb. and the pressure released in order to measure the permanent sets. The tank was then tested to 900 lb., the pressure released, and permanent sets measured both inside and outside the tank.

The results of the test of the manhead with reinforcing ring are shown in Fig. 11 and Table 5. The stresses up to 600 lb. pressure were comparatively small, the strains being less than one-third of those measured on the standard manhole construction. On raising the pressure to 900 lb., however, the metal at the edge of the major axis of the manhole was deformed, although the deformation was not as great as in the old head. In fact, the whole head was strained above the elastic limit and was highly deformed, tending to assume the shape of an ellipse under the internal pressure. This deformation, combined with the effect of the manhole cover, resulted in excessive strains being imposed upon the stiff reinforcing ring. The bending moments thus set up caused the reinforcing ring to expand at the outer diameter and the cylindrical ring to become slightly conical. This is shown by the fact that the maximum permanent set at the inner end of the cylindrical ring was negligible. It was this conical deformation that caused the high strains shown in the curves at 900 lb. A head properly shaped to minimize head deformation under high internal pressure should eliminate these superimposed bending moments.

On the retest the heads showed no further deformation, and the measured stresses approximated the calculated stresses. As the test showed that the tank was safe, it was accepted and put into service.

TABLE 5 STRESSES AND STRAINS AROUND MANHOLE

	Maximum stress measured near manhole, standard construction	Stresses near manhole with ring reinforcement		
		At edge	1 in. from edge	2 in. from edge
At 300 lb. working pressure.....	44,000 lb. per sq. in.	18,000 lb. per sq. in.	11,900 lb. per sq. in.	9300 lb. per. sq. in.
At 600 lb. working pressure.....	0.00559*	0.00178*	0.00135*	0.00124*

* Measured unit deformation or strain, inches per inch.

SUMMARY

The results of the analysis of the deformation and distribution of stress in the shell and heads of this tank subjected to repeated high test pressures appear to warrant the following general conclusions:

1 The common formulas for designing the shells of ordinary pressure vessels give reasonably accurate determinations of the stresses. The measured stresses in the shell applied in the two-dimensional formulas are in close agreement with the design stresses computed by these common pressure formulas.

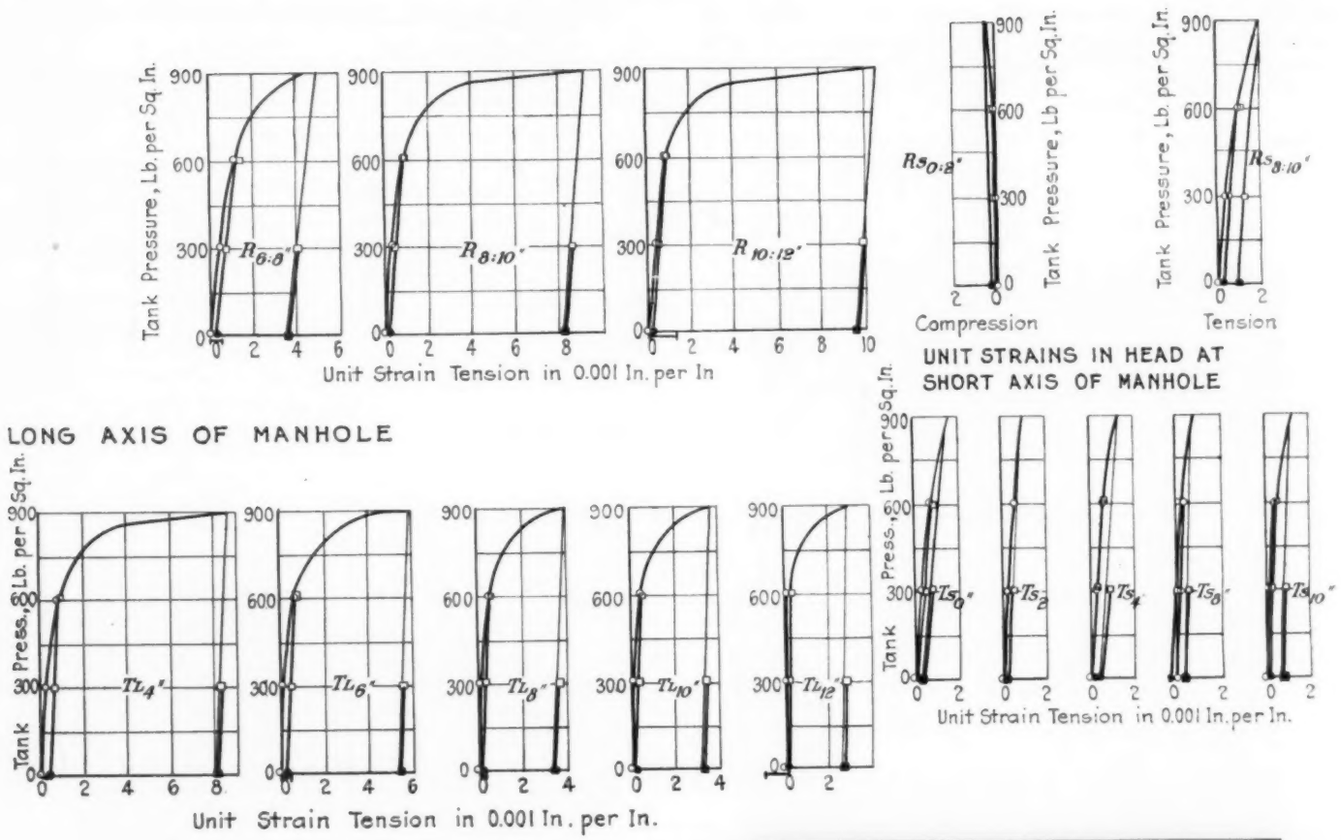


FIG. 11 (Continued from page 131)

2 The actual strain stress (the measured strain multiplied by Young's modulus) agrees very closely with Clavarino's formula for closed cylinders. In using this formula for material under three-dimensional stresses, it appears that lower elastic-limit values than those determined in tensile tests should be used. Otherwise this formula in designing may give stress values that err on the side of danger.

3 Secondary stresses in the shell, manifested as superimposed bending stresses, are developed by irregularities in rolling, fabrication, or non-conformity of the shell to an accurate circular section. These affect the stress intensity, resulting in the combined stresses slightly exceeding the elastic limit in the first test, as shown by the strain measurements. These irregularities are either completely ironed out by high internal pressure, as shown by the close agreement of measured stresses with theory after the first pressure application, or their influence is materially reduced, resulting in lower stress intensity. The stresses under reapplication of pressure do not exceed the elastic limit and are proportional to the pressure.

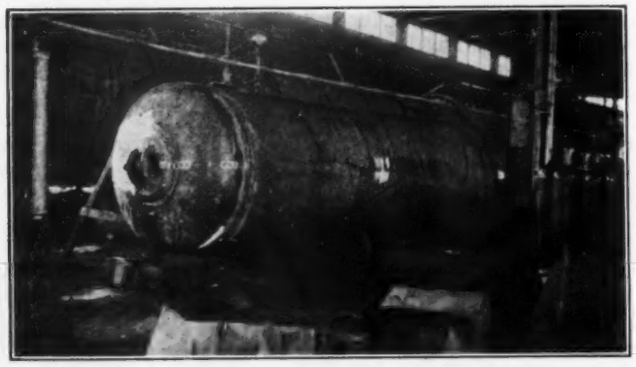


FIG. 12 GENERAL VIEW OF REPLACED MANHEAD SHOWING LOCATION OF 2-IN. GAGE LINES AROUND MANHOLE AND KNUCKLE
(Strain measurements were made at corresponding points on inside of tank to determine permanent sets.)

FIG. 13 LUDERS LINES AT THREE TIMES DESIGN PRESSURE
(Scaling at edge of long axis of manhole, but at no other point around opening.)

These results indicate that high test pressures improve the condition of the tank shell.

4 Very high bending stresses are imposed at head knuckles. A head with large radius of dish and small knuckle radius under high pressure appears to act more as a dished plate supported at the rim than as a section of a sphere, the basis of present design. Under the action of the internal pressure against the head, the knuckle tends to flatten out, setting up high compression hoop strains. The maximum tensile strains occur on the inside of the knuckle in a radial direction and result from bending in this direction as the knuckle radius is increased by the pressure. The results show that the stresses after the metal is deformed by a given test pressure are within the elastic limit unless this pressure be exceeded, in which case the deformation will continue until the head is readjusted to the higher pressure. It seems desirable to increase the corner radius, or redesign the head in closer conformity to the shape it tends to assume under internal pressure, in order to minimize the stress intensity and avoid the excessive and possibly dangerous tensile strains that may be developed at the inside of the knuckle.

5 The highest strains in a tank under internal pressure occur around the manhole. In some cases they are excessive or even dangerous at operating pressure, and in other cases may become dangerous at slightly higher pressures. The results from the first head with standard manhole construction show that because of the excessive strains around the manhole opening, continued yielding occurred at this point on each application of a pressure slightly in excess of three times the design pressure. Head failure through the manhole such as occurred in this tank is inevitable under these conditions. Stress concentrations around holes or points of discontinuity, probably combined with bending action imposed by the manhole cover and head deformation, are the causes for such excessive strains being developed around manholes.

6 The strain measurements and test data of this investigation show that shells of pressure vessels designed and constructed in accordance with usual practices are entirely satisfactory and that welding can be safely used for fabrication, but it appears that the commonly used formulas for head design and manhole reinforcement are inadequate for high-pressure tanks. More consideration should be given to proper design of heads and manholes of pressure vessels, irrespective of the method of fabrication, if they are to be constructed to have the same factor of safety as in the shell.

The World's Fighting Ships

THE new volume of Jane's Fighting Ships, the famous British naval encyclopedia, is enriched by numerous photographs of very recent date, depicting all the latest ships of the British and other navies. Three views of H.M.S. *Nelson* are given, besides a diagram, and these, together with the particulars which the Admiralty has released, enable a clear impression to be formed of this ship and her sister, the *Rodney*. The revolutionary nature of their design is indicated by the distribution of the big guns, all of which are mounted forward; the withdrawal of the machinery spaces toward the stern, and the substitution of a huge control tower for the tripod foremast, which was so prominent a feature of earlier ships. In gun power, and possibly in protection also, these ships are unequaled. Their speed still remains an official secret, but if the constructors have been able to go above 23 knots they will have performed wonders. In view of the large program of cruiser construction which is now under way, it is satisfactory to have plans and particulars of the *Kent* class. The design appears to have been well thought out. It provides for a displacement of 10,000 tons—exclusive of fuel—a speed of 32 knots, and a main armament of eight 8-in. guns in twin turrets at bow and stern. As the freeboard is high and the hull flush-decked, the ships should be more weatherly and comfortable than the low-lying cruisers that were built during the war. Including the *Canberra* and *Australia* for the Commonwealth Government, eleven ships of this type are now under construction, and two more are to be laid down before next April. Another interesting addition to the Fleet is the cruiser-minelayer *Adventure*, which began her trials in November. Her machinery is believed to consist of Parsons turbines, with Diesel engines for cruising purposes, but no details of the installation have so far been given out. Her present armament of four 4.7-in. guns is so inadequate that we hope Fighting Ships is well informed when it suggests that five 5.5-in. guns may eventually be mounted instead. The number of mines carried is said to be one thousand. Some excellent views are given of the battleship *Warspite*, as reconstructed, with the fore funnel trunked into the second and the bridges rebuilt.

Turning to foreign navies, visual evidence is afforded of the modernization programs which are a feature of post-Treaty development. All the six Dreadnoughts of the French Navy have been rebuilt, involving a complete change in their appearance. In the six oldest American battleships the uptakes are led into a single funnel, new masts have been stepped, and airplane catapults installed. Japan has transformed the *Nagato* and the *Mutsu*, which now have much the same funnel arrangement as the *Warspite*, and her other battleships are a mass of tophamper. The new French cruisers, destroyers, and submarines built since the war are illustrated for the first time. The surface craft are beautifully modeled, especially the destroyers of the *Simoun* class, and the majority have done well on their steam trials. The latest type of French leader, now being built, displaces 2650 tons, is engined for 36 knots, and armed with five 5.5-in. guns. It is therefore a light cruiser in all but name. Perhaps the most striking vessels portrayed in the book are the Japanese cruisers *Furutaka* and *Kako*, remarkable alike for the weight of armament in proportion to tonnage and their extraordinary appearance. Displacing no more than 7100 tons, and capable of 33 knots speed, they carry six 7.5-in. or 8-in. guns singly mounted on the center line, three of the gun houses being forward and three aft, with the middle one of each group superimposed. The first and second funnels are trunked together, and immediately abaft the third is an airplane hangar and a catapult. To us these ships appear topheavy, but if they are reasonably good sea boats their designers have opened up a new vista of possibilities as regards cruiser construction.

There is a certain sameness about most of the 10,000-ton "Treaty" cruisers now being built at home and abroad. In England, France, and Italy a main armament of eight 8-in. guns has been adopted, but Japan is putting nine into her new ships, and the American type is to have ten. Speeds vary from 32 to 34 knots, and armor protection is of course very scanty, though our ships are credited with a 4-in. deck amidships. Submarines show a progressive increase in dimensions. Larger boats than the X.1 are now on the stocks in America, France, and Japan, and the coming of the real submarine cruiser, with high speed, heavy armament, and almost unlimited endurance, would seem to be only a question of time. The identification of warships at sea will be rendered more easy by the stippled silhouettes which are gradually replacing the old block elevations. In the British section the change is already complete, and there can be no question as to the superiority of the new system. In order to mark the thirtieth year of publication, a brief account of the genesis of Fighting Ships is given and specimen pages from the first edition are reproduced. The present volume does credit both to editors and publishers.

In Brassey's Naval and Shipping Annual, 1927, Sir George Thurston turns his attention to the destroyer, which he considers to have fully justified its perpetuation. He advocates a type somewhat larger than our present flotilla leaders and mounting a far heavier armament. The following are the chief points of the design: Length, 400 ft.; displacement, 2900 tons; speed, 36 knots; armament, ten 4.7-in. guns, twin-mounted; at least sixteen 40-mm. A.A. guns, and sixteen 24-in. torpedo tubes. Such vessels would, however, be very expensive, and we think that a smaller and cheaper type would be preferable, having regard to the large number of destroyers that the navy requires.—*The Engineer* (London), December 10, 1926, pp. 640–641.

Stimulation of Research in Pure Science Resulting from Needs of Engineers and of Industry

Beginning of Appreciation of Pure Science—Appreciation of Knowledge—Part Played by Industries in Scientific Work—Classification of Research—Stimulation of Research—Contributions from Engineering Needs

By WILLIS R. WHITNEY,[1] SCHENECTADY, N. Y.

THE appreciation of *pure* science in all civilized countries has steadily increased over an indefinitely long period, but it is quite common to look back to Roger Bacon, or to the beginning of the use of printing presses, or to Francis Bacon, or to some other definite point whence the start seems to have been made. The author doubts if any one time can be chosen over another. The first living cell which made new motions concluded as definitely and acted as consistently as a result of its pure experiments as we do. We are still infinitely removed from complete appreciation, and are therefore not far from the amoeba. The laws illustrated by the amoeba tell us that there are good, bad, and indifferent activities, that countless promising experiments may be made, that we may learn after the experiment whether we are better or worse off, and finally that the habit of experimenting, or the character of curiosity, may be perpetuated, just as all existing plants and animals have been perpetuated.

But to shorten the story, we shall start with Francis Bacon and then proceed at once to the Invisible College of England, about 1645. In 1662 this became the Royal Society for Improving Natural Knowledge, and it has been improving it ever since. Thousands of other groups of scientists and engineers, aiming to advance civilization, have coöperated to the same end.

Appreciation of Knowledge

Gradually in each country the accumulating appreciation of knowledge doubtless determined the increasing growth of organized experimental research in the schools and universities. This in turn plainly acted on the growing industries, and a closer and closer coöperation became effective. Thus from a time when the monasteries were the schools and students cloistered monks, the old countries became ever more alert to the value of science in human affairs, and college training put men into service through the professions or the industries. These in turn still further promoted the idea of advancement of learning. Cambridge in England, in the author's day, revolutionized pure physical science, and Cambridge in America enjoyed its first scientist college president.

Strangely enough, it has always resulted that the most remote observations, the most unusual experiments, the most unexpected phenomena, the most insignificant new facts, and the most unnecessary discoveries developed into subsequent needs and necessities, but the needs have not usually pointed ahead toward new discoveries.

It is a minor but noteworthy fact that in recent years industries in all countries have taken part in scientific work and employed on the whole a rapidly increasing number of engineers and scientists. Interest in new knowledge is no longer confined to the universities, and while it is true that there has been a recognized division of labor such that colleges and universities have usually done pioneer work and industrial engineers have usually expanded or developed new truths for general appreciation or consumption, it is also true that today one may find in the world's scientific literature about as many publications of general scientific value from industrial laboratories, state and private laboratories, as from colleges and universities. It is becoming the deliberate habit of industries to support the sciences on which they are based. Perhaps the most marked case in our country, and certainly one which deserves honorable mention, is the telephone group. Its publications are numerous, highly scientific, and equal in every way to those of the foremost physical societies. All of this betokens a healthy attitude, but no better than we ought to expect from intelligent people who have the history of the past in mind.

The author was asked to consider research in pure science with reference to the contributions it receives from industry. He does not intend, in fact he could not, distinguish in that way, though he made an attempt. What he will say is a natural development of an attempt to divide or locate scientific research either as to quality or source, and he concludes by still more highly appreciating the science of schools and the contributions of engineers and industries.

Classification of Research

All research in science seems good to the author, and artificial distinctions as to kind and source are invidious. Research will be extended because people see more and more clearly how it works. Pure research is merely uncovering parts of infinite stores whose value, often appreciated, is never anticipated. From the subject, one would expect pure research and the animation which necessity gives it to be dealt with, but *pure*-science research is not so animated. So it will be necessary to clarify the field with definitions, and the recent classification of Balls[2] is accepted by the author. No attempt will be made to repeat the eight [(*a*) to (*h*)] classes, but, beginning with so-called "pure" research, his idea that it is typified by university research is accepted, also that it has three degrees of freedom, i.e., freedom in method, aim, and subject. Six other classes, which carry all the other combinations of freedom, are defined, and finally class (*h*) is reached. In this there is no degree of freedom, and it is represented by "testing" and "works-control laboratory work." Since the author accepts these definitions, he cannot attribute pure-science research to definite external causes. It is due to internal inquisitiveness of individuals. We may imagine, if we wish, that all scientific work is done because of future needs, but if we use the term "pure science" at all, then we should thank Mr. Balls for classifying the research types, however stimulated. He has given us terms to include all so-called impure and applied research.

Type (*a*) interests us most. The prime stimulus of this scientific research is curiosity. The most important function of colleges and universities is appreciating inquisitiveness and educating curiosity. There is often a tendency to train men for predetermined mechanical work in which perhaps only the teacher feels the mental stimulus. This is intellectual myopia.

As Mr. Balls gives us eight classes, we can probably place any given research in some one of them.

Industry and its engineers call for a great deal of new or more accurate data [classes (*b*) to (*g*) of Balls]; some of it is splendid material for engineering students; it teaches them careful manipulation and it helps introduce them to their chosen fields; but it may be so ill used as to habituate one in seeking only the anticipated object of one's forced or hurried work. This forces the student to bridle or even kill his curiosity, and may train him only as a thoughtless automaton. For example, steel, usually used cold, is now being used hot, and we need strength tests at high temperatures. Is this research in pure science? It is free in method, but not in subject nor aim. Having that one degree of freedom, it is type (*d*) of the Balls scale. Under such classification one may suggest that it is the duty of the steel industry to look out for (*d*) as it always does for class (*h*), for example.

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[1] Director, Research Laboratory, General Electric Company.

Presented at the Annual Meeting of the American Association for the Advancement of Science, Section M (Engineering), Philadelphia, Pa., December 29, 1926.

[2] The Classification of Research, by W. Lawrence Balls. *Nature*, August 28, 1926, pp. 298–299.

With a quarter-century's experience with existing varieties of research, from pure academic, with three degrees of freedom, to "trouble shooting," with no freedom at all, the author sees that neither he nor any one else completely comprehends research. This is very fortunate, because we may still learn something about it through research. Time might be wasted by facetiously recognizing only two types, useful and useless; but there can be no such division in fact.

Now, the author was asked to point out the stimulation of research in pure science which has resulted from the needs of engineers and of industry but he feels helpless, inquisitive, and speculative. Does it work that way?

STIMULATION OF RESEARCH

Engineers generally do not want pure research, though they want it to have been done. Perhaps one could call this stimulation. They frequently ask for things which are clearly definable but non-existent. For engineering, things must be tangible and contingent. Engineers have pressing problems to solve, and the words "pure research" as a cure for their immediate wants usually connote only postponement or disappointment. Pure research, to be good, is usually random (beyond the edge of knowledge), and is mainly activated inquisitiveness. Engineers never call the products of such research "necessities" until after the engineering event. Every good engineer is too perpetually busy to be much attracted by what is called pure research, however well he may know its laws of birth or heredity. To him it is productive but it is not production.

There *is* a stimulation of pure research which, doubtless, deep down in the tendencies of research men, is a natural development of the sense for general survival and of amelioration. Most of the so-called pure research that the author has known about was at the time as remote from engineering as human effort could make it, and certainly it did not develop, nor was it visibly stimulated, by recognized needs of engineering. To the author's mind, engineering is using material knowledge with safety for our convenience. The more knowledge available, the better; the more accurate it is, the safer. Therefore, whether the individual research man may feel it or not, he is working for future engineers. In that way pure research is certainly stimulated by engineering.

In geographical discovery there is an obvious parallel. The pioneer, a sportsman, or a mere trapper, takes all sorts of risks, travels with difficulty through all kinds of unknown territory, sets various traps or fishes for whatever bites. When he returns to civilization he trades off his catch and his new knowledge. No thought of engineering was in his mind. A real woods pioneer might remain silent if he realized that by describing a certain water fall he was insuring its early development. He would not promote a power site nor a nature-destroying hamlet. Nevertheless the pioneer is unconsciously part of the continually growing thing which we call civilization.

The three-degree research man is much like this pioneer. Usually he does not weigh the needs of engineers, but rather makes the discoveries which interest him. Commercial uses of his discoveries often seem uninteresting, and sometimes even distasteful to him. For example, a pure-research man, studying the parasites, or the life habits of some lowly insect, makes it possible for an entomological engineer later to save the apple crop of Australia by importing there the enemy of the destructive aphis.

This principle of random research, call it the blind principle if you will, is evident everywhere. In radio, for example, when crystal sets were the key to receiving stations, engineering needed improvements in efficiency, increase in range, and reduction of cost. Engineering refinements of iron filings, cats' whiskers, and synthetic crystals were soon exhausted. But pure research had already disclosed knowledge which made vacuum tubes a promising new territory. Without the random inquisitive research in vacuum phenomena, extending all the way from the early experiments of Hittorf and Edison through Thomson, Richardson, Fleming, De Forest, Langmuir, and many others, radio might more logically have sought its engineering advances in the saps of trees or in ectoplasm than in a vacuum.

To the author's mind, the wonderful trait of inquisitiveness in man has kept so far ahead of recognized needs (that is, of engineering) that unapplied assets can still be tapped for further amelioration. As this has been a law from the time when the amoeba first started to move, the author feels that encouraged curiosity is the safest criterion of an improving civilization. If we assumed that man should research only when he felt the need of a definite thing, he would continually butt his empty head against a wall, and always the wrong wall.

As J. J. Thomson has said: "Discoveries are not terminals, but avenues." They are not places to stop, but ways to proceed; and the more there are, the more new ones may be opened. The more we subtract from the unknown, the greater and more useful it becomes.

Our ancestors who engineered the explored West recognized few of our present needs. Canal boats or ox teams, slowly advancing to fertile lands, were recognized needs, and home-grown food and home-made clothes were necessities. The grandchildren need mile-a-minute transportation, with simultaneous dining and sleeping luxuries. They demand discoveries in food, raiment, comforts, and news from everywhere, integrated over all time. The earlier conception of needs extended to a little faster packet boat, a little heavier oxen, deeper furrows, bigger farms, and a longer workday. Similarly, we in our turn blindly think we conceive the needful. Just as changes resulting from curiosity and research have made us forget the needs for canal boats, oxen, and even twelve-hour days, so probably our descendants will find more in creation than do we today.

Chemical engineers, anticipating needs for liquid fuels, exhaust the known methods of production. Research chemists, perhaps ignorant of fuels, inquisitively study laboratory curiosities like catalysis, or they test the correctness of new mathematics like the Helmholtz and Nernst equations, the Le Chatelier principle, or the kinetic gas theory. They thus store shelves with principles and data which later become indispensable.

An inquisitive engineer, stimulated by the need for change, tries one of these novelties, and soon we hear of synthetic oils and alcohol. The same scientific researches which guide engineering in one such field usually serve many others.

In refrigerating engineering, for example, the history of ammonia, of sulphur dioxide, of methyl chloride, or of butane, does not disclose stimulation of the engineer's needs. These four avenues proceed ninety degrees apart, and only cross where the refrigerating engineer happened to read the names of the avenues. Had he been a fertilizer engineer, for example, he might have called new knowledge of ammonia a necessity, but scarcely that of sulphur dioxide.

Engineers are busy with such things as buildings, bridges, automobiles, locomotives, subways, power plants, railways, pipe lines, and airplanes. Each became a necessity only after it had been discovered, reproduced, and tested. It wasn't a perfectly obvious thing to build the first bridge. No engineer needed it. A tree fell across a creek and some inquisitive animal shinned over. This first bridge research resembles much of pure research, a kind of "monkeying," but it is more useful than "aping," as Robinson has pointed out. So also many inquisitive fellows burned their fingers at natural fires long before any one thought of controlling heat or making fires artificially. Some curiosity seeker later produced hand-made fire, just as inquisitive men, from Hero to Watt, played with steam.

Obviously, it is wrong to overlook the enormous stimulation due to coöperation between research and industry or the mutual relationship of researcher and engineer. The author is only contending against the thought that any one can long foresee what may become our major needs and thereby circumscribe pure-science research. None of our necessities was planned that way, not even the wheel. Wheels came into engineering, as steam did, through curiosity. Electricity came into engineering after years of accumulated and recorded inquisitiveness, including Faraday's work. Chemistry was the plaything of magicians, monks, and pure-science teachers centuries before chemical engineering became a comprehensible term.

As there is no end to new knowledge, so engineering must always grow. Every engineer looks longingly at the properties he employs, to see if they can be extended, and this leads to endless research

of direct utility. But if pure science has any meaning, this is not it. A reason for saying so is the fear that we Americans may grow scientifically near-sighted. We may mistakenly think education the mere recording or measurement of things. The mechanical operations may submerge the mental, and minds be shut in instead of opened out. Transportation was not exclusively advanced by breeding fast horses. Trimming sails did not lead to their displacement by steam. The telephone came without improving voices, and radio has come without improving wires. Aeronautic development comes more nearly through curiosity aroused by explosions than through feathers. We seem to get ahead by uncovering lightly covered creations, rather than by stretching what we know further than it will go.

University-trained men who find themselves in industrial work are not naturally divorced from their earlier scientific associates, nor do they cease to take interest in pure science. Engineering thereby increasingly contributes to science, and industries cooperate with educational institutions. The president of a corporation needs be no less interested in pure science than is a science teacher. The one may enjoy his method of contribution as well as the other. It would indeed be difficult to differentiate between the coöperate efforts of a Kodak Park or a Nela Park laboratory, as shown by its scientific publications, and an equal volume of pure-science publications from colleges. It may be unusual to attribute the same kind of interest in science on the part of the officers of the respective institutions. It exists, however, and indicates the unity of motive which well-educated people possess.

We advance more often by finding in nature that which we may learn to use than by making or forcing from nature that which we think we want, so there are the different classes of research. The unhampered, pure science seems best fitted for universities. Although called "random" research, it is neither casual nor accidental. It is the most natural activity of the good teacher in every science. His field is expanding, and he will teach better if he knows its forests and takes part in their clearing. He needs no better guide than his inquiring mind. The research engineer, on the other hand, has some specific aim. Having entered a field already revealed by class (*a*) research, he plows straight furrows and stops only to remove obstructions. Thereby he also uncovers new knowledge, but he is not free to wander. If gold or coal lies beneath the rock disturbed by his plow, he may find it, but research men, using three degrees of freedom, are more likely to discover there everything but farm products. One aims directly to produce, the other to learn, and both are absolutely necessary to our advance. There is a natural pressure in competition to encourage the industrial needs, but only an intelligent foresight can insure pure, orderly research, because curiosity is usually restrained.

CONTRIBUTIONS FROM ENGINEERING NEEDS

These are generalities, and fortunately every subject and every man is complex. So it is that contributions also come from engineering needs. For example: electrons are discovered, and their uses become needs. Pure-science research is followed by the seven other classes. Electron emission of tungsten is made useful in radio and the phenomenon is studied as broadly and freely as possible. Other elements, such as thorium, are thus brought into radio service. The theoretical conceptions and mathematical conclusions are published by men in the industry and the advance of the science and the art accelerated. This process is relatively complete in electrical engineering, but much less so in other research fields. It is clear that every item of new knowledge of electricity probably can be made to do service somewhere. It is relatively a new, compact, orderly, but unlimited field. Research in it could not be so pure, so unattached, so remote as not to fit a use. Close coöperation is to be expected in it between its detached pioneers in colleges and those who plow and reap elsewhere, and a single scientist may do much of each.

Mechanical engineering is in a similar position, and chemical engineering is rapidly reaching it. Biology, heredity, psychology, on the other hand—in fact, the greater number of sciences—still lack engineering coöperation. Through pure research there will certainly be continually made other as needful and yet unexpected disclosures as those we now enjoy, and perhaps in entomology, for example, there are more interesting possibilities than were seen in all physics before electricity was pioneered out of it by Faraday.

Bacon said of the Greeks that they had no antiquity of knowledge and no knowledge of antiquity. We see now how well they used what they had. But we ourselves have an accumulation of experimental facts of all kinds which, since the discovery of printing and the establishment of national and international scientific societies, has never ceased expanding. It is upon this stock of tested experience that engineering usually draws. The stimulation responsible for that stock is primarily natural curiosity, and it must be developed in education. The asset of engineering is exact knowledge. The valuable attributes of research men are conscious ignorance and active curiosity. For an engineer, "safety first" is a good slogan, but "safety last" is better for the man of research.

H. E. Armstrong said: "The pursuit of science is necessarily an *anti*-human practice, as it involves an all but impossible self-abnegation." It is more nearly an *ante*-human practice, as it first discloses to human ken created supplies not otherwise humanly available.

Curiosity may be limited, but Creation is unlimited. Free or untrammeled research has given engineering far greater bequests than could be suggested by needs or preconceptions. As this reaction is more in evidence now than ever before, it will continue, and our first interest is to encourage the educated engineering mind. The obvious or pressing needs of industry can be relatively easily and safely cared for as at present.

We ought to realize that there may be some more valuable use of knowledge and truth than commercial developments, and by aiming at the full appreciation of creation we may do more than simply conquer and control our local environment. Perhaps industrial uses of new knowledge are, after all, only by-products or ways for advancing to something better. As Anatole France said: "The present is being built on the foundation of the wisdom of the past, and is destined for the use of the future."

One Plant Burns Nine Fuels in Suspension

OF PARTICULAR interest in discussing fuels is the arrangement used at the Iron Mountain, Mich., plant of the Ford Motor Co. Here nine different fuels are burned in suspension in a standard type of pulverized-coal furnace with air-cooled hollow walls. Pulverized coal in this case forms only a small portion of the fuel burned. Almost 100 per cent of the fuel burned at Iron Mountain consists of industrial by-products from a large chemical plant and woodworking factory. Dry chips, shavings, and dry sawdust are produced in a large body plant, and these three fuels are burned in suspension. Wet sawdust and hogged fuel are produced in the sawmill and, if not used in the chemical plant, can be burned on grates at the bottom of these furnaces. The chemical plant, which takes most of the wood waste from the woodworking processes, supplies wood gas, oil, and tar as well as charcoal to the plant as by-products of the wood-distillation process which it carries on. The gas is piped direct to the furnaces, the oil and tar are handled by standard oil-burning equipment, and the charcoal is pulverized and handled with pulverized-coal equipment. To supplement this arrangement, pulverized coal was added.

In plants like Columbia and Trenton Channel where the coal has an initial moisture of 3 or 4 per cent the drying of coal is not always necessary except in cases of emergency. At Cahokia, however, the coal, which is Belleville and Kathleen screenings, has an initial moisture content as high as 11 per cent. The driers, which are of the flue-gas type, reduce this moisture to 8.5 per cent, and it is further reduced to 5 per cent in the pulverizing mills. At Valmont, burning lignite having a moisture content of anywhere from 19 to 28 per cent, it is found that as far as combustion is concerned this lignite can be burned without drying. Some trouble, however, is encountered with bridging in the bins when the moisture content is above 19 per cent, so it is usually dried to this point. In addition it is found that drying increases the capacity of the mills from their nominal rating of 6 tons to about 10 tons.—*Power Plant Engineering*, January 1, 1927, p. 11.

The Nation and Science[1]

By HERBERT HOOVER, SECRETARY OF COMMERCE

I SHOULD like to discuss with you for a few moments certain relationships of pure- and applied-science research to public policies, and above all the national necessity for enlarged activities in support of pure-science research.

Huxley was perhaps not the first, but at least he was the most forceful in his demand that preliminary to all understanding and development of thought there should be a definition of terms. Men in the scientific world will have no difficulty in making a distinction between the fields of pure and applied science. It is, however, not so clear in industry nor in our governmental relations, and sometimes even in our educational institutions.

At least for the practical purpose of this discussion I think we may make this definition: that pure-science research is the search for new fundamental natural law and substance, while applied science is clearly enough the application of these discoveries to practical use. Pure science is the raw material of applied science. And the two callings depart widely in their motivating impulses, their personnel, their character, their support, and their economic setting. And these differences are the root of our problem.

As a nation we have not been remiss in our support of applied science. We have contributed our full measure of invention and improvement in the application of physics, in mechanics, in biology and chemistry, and we have made contributions to the world in applied economics and sociology.

Business and industry have realized the vivid values of the application of scientific discoveries. To further it, in twelve years our individual industries have increased their research laboratories from less than 100 to over 500. They are bringing such values that they are increasing monthly. Our federal and state governments today support great laboratories, research departments, and experimental stations, all devoted to applications of science to the many problems of industry and agriculture. They are one of the great elements in our gigantic strides in national efficiency. The results are magnificent. The new inventions, labor-saving devices, improvements of all sorts in machines and processes in developing agriculture and promoting health are steadily cheapening cost of production; increasing standards of living, stabilizing industrial output enabling us to hold our own in foreign trade; and lengthening human life and decreasing suffering. But all these laboratories and experiment stations are devoted to the application of science, not to fundamental research. Yet the raw materials for these laboratories come alone from the ranks of our men of pure science whose efforts are supported almost wholly in our universities, colleges, and a few scientific institutions.

$200,000,000 Spent Annually in America in Applied-Science Investigations

We are spending in industry, in government, national and local, probably $200,000,000 a year in search for applications of scientific knowledge—with perhaps 30,000 men engaged in the work.

I should like to emphasize this differentiation a little more to my non-scientific audience. Faraday in the pursuit of fundamental law discovered that energy could be transformed into electricity through induction. It remained for Edison, Thomson, Bell, Siemens, and many score of others to bring forth the great line of inventions which applied this discovery from dynamo to electric light, the electric railway, the telegraph, telephone, and a thousand other uses which have brought such blessings to all humanity. It was Hertz who made the fundamental discovery that electric waves may traverse the ether. It was Marconi and DeForest who transformed this discovery into the radio industry. It was Becquerel who discovered the radioactivity of certain substances, and Professor and Madame Curie who discovered and isolated radium. It was Dr. Kelly who applied these discoveries to the healing art and to industrial service. It was Perkins who discovered the colors in coal-tar by-products. It was German industrial chemists who made the inventions which developed our modern dye industry. It was Pasteur who discovered that by the use of aniline dyes he could secure differentiation in colors of different cells, and this led to the discovery of bacilli and germs; and it was Koch and Ehrlich who developed from this fundamental discovery the treatment of disease by antitoxins.

And so I could traverse at great length these examples of the boundaries and the relations of these fields of pure and applied science.

There is a wide difference in the mental approach of the men engaged in these two fields of scientific work. The men in pure science are exploring the frontiers of knowledge and they must necessarily do so without respect to reward or to its so-called practical benefits, whereas the men engaged in applied-science research have long since demonstrated that it pays in immediate returns. It brings such direct rewards as to generate its own steam mostly through the Patent Office. There is seldom any direct financial profit in pure-science research, although its ultimate results are the maintenance of our modern civilization and are the hopes for the future.

For all the support of pure-science research we have depended upon three sources—that the rest of the world would bear this burden of fundamental discovery for us, that universities would carry it as a by-product of education, and that our men of great benevolence would occasionally endow a Smithsonian or a Carnegie Institution or a Rockefeller Institute. Yet the whole sum which we have available to support pure-science research is less than $10,000,000 a year, with probably less than 4000 men engaged in it, most of them dividing their time between it and teaching.

Pure-Science Activities of Country Have Diminished During the Last Decade

Some months ago our leading scientists in reviewing the organizations of pure science of the country were discouraged to find that their activities had been actually diminished during the last decade, whereas if these laboratories are to furnish the increasing vital stream of discovery to our nation and our normal part of the world, they should have been greatly enlarged. Moreover, they discovered that the pressures of poverty in Europe were taking a worse toll of pure science abroad.

The causes in the United States are not far to seek. They arise from two directions: First, 80 per cent of the men devoted to pure-science research with us are in our scores of universities and colleges. Our universities have doubled in the number of their students. Their prewar endowments and income have been depreciated by the falling dollar. New resources have been given many of them, but not enough to handle their new burdens of teaching. All of this has led them to more and more curtailment and the suppression of expansion in pure-science research in order that they might attend to the immediate problem of education. Thus the four or five thousand men in the United States who have demonstrated their ability for research of this character are not applying themselves in this direction so much as they are applying themselves to the education of the youth. Teaching is a noble occupation, but other men can teach, and few men have that quality of mind which can successfully explore the unknown in nature. Not only are our universities compelled to curtail the resources they should contribute in men and equipment for this patient groping for the sources of fundamental truth because of our educational pressures, but the sudden growth of industrial laboratories themselves and the larger salaries they offer have in themselves endangered pure science by drafting men from the universities. This is no complaint against our great industries and their fine vision of the application of science. It simply means we must strengthen the first line of industrial advancement—pure-science research.

These men of pure science are the most precious assets of our country, and their diversion to teaching and applied science reduces the productivity which they could and should give to the nation. It is no fault of their own, but it is the fault of the nation that it does not give to them and to the institutions where they labor a sufficient support.

There is no price that the world could not afford to pay these men

[1] Sigma Xi Lecture before the American Association for the Advancement of Science, Philadelphia, Pa., December 28, 1926.

who have the originality of mind to carry scientific thought in steps or in strides. They wish no price. They need but opportunity to live and to work. No one can estimate the value to the world of an investigator like Faraday or Pasteur or Millikan. The assets of our whole banking community today do not total the values which these men have added to the world's wealth.

Some scientific discoveries and inventions have in the past been the result of the genius struggling in poverty. But poverty does not clarify thought, nor furnish laboratory equipment. Discovery was easier when the continent was new. Discovery nowadays must be builded upon a vast background of scientific knowledge, of liberal equipment. It is stifled where there is lack of staff to do the routine work and where valuable time must be devoted to tending the baby or peeling potatoes, or teaching your and my boys. The greatest discoveries of today and of the future will be the product of organized research free from the calamity of such distraction.

DAY OF THE GENIUS IN THE GARRET, IF IT EVER EXISTED, HAS PASSED

The day of the genius in the garret has passed, if it ever existed. The advance of science today is by process of accretion. Like the growth of a plant, cell by cell, the adding of fact to fact some day brings forth a blossom of discovery, of illuminating hypothesis, or of great generalization. He who enunciates the hypothesis, makes the discovery, or formulates the generalization, and thus brings forth the fine blossoms of thought, is indeed a genius, but his product is the result of the toil of thousands of men before him. A host of men, great equipment, long, patient scientific experiment to build up the structure of knowledge, not stone by stone but grain by grain, is now our only sure road of discovery and invention. We do have the genius in science—he is the most precious of all our citizens. We cannot invent him; we can, however, give him a chance to serve.

And the more one observes, the more clearly does he see that it is in the soil of pure science that are found the origins of all our modern industry and commerce. In fact, our civilization and our large populations are wholly builded upon our scientific discoveries. It is the increased productivity of men which has come from these discoveries that has defeated the prophecies of Malthus. He held that increasing population would constantly lower the standard of living among men until the pressure of subsistence upon population would limit its number by starvation. But since his day we have seen the paradox of the growth of population far beyond anything of which he ever dreamed, coupled with a constantly increasing standard of living. This result would be impossible but for the men of fundamental scientific research and discovery. In fact, there is for the future but one contestant in the race with the principle of Malthus, and that is pure science. If we would have our country increase in its standards of living and at the same time accommodate itself to an increasing population at the rate of more than 15 million each decade, we must maintain the output of our pure-science laboratories.

The wealth of the country has multiplied far faster than the funds we have given for these purposes. And the funds administered in the nation today for it are but a triviality compared to the vast resources that a single discovery places in our hands. We spend more on cosmetics than we do upon safeguarding this mainspring of our future progress.

AVENUES ALONG WHICH MORE LIBERAL SUPPORT TO PURE-SCIENCE RESEARCH MUST BE SOUGHT

But to return to my major theme—How are we to secure the much wider and more liberal support to pure-science research? It appears to me that we must seek it in three directions: First, from the government, both national and state; second, from industry, and third from an enlargement of private benevolence. We have long since accepted the obligation upon the state to provide universal and free education. We have advanced it further than any nation in the world. Yet the obvious function of education is to organize and transmit our stock of knowledge—it is not primarily concerned with the extension of the borders of knowledge except in so far as the process is educational. It seems to me that we must accept the fact that the enlargement of our stock is no less an obligation of the state than its transmission. As a nation we must have this enlargement of stock if we would march forward. And the point of application is more liberal appropriations to our national bureaus for pure-science research instead of the confinement as today of these undertakings to applied-science work. And we must have the more liberal support of pure-science research in our state universities and other publicly supported institutions.

Our second source of support must come from business and industry. You are aware of the appeal in this particular from the National Academy of Sciences of a year ago—that they might be entrusted with a fund largely for the better support of proved men now engaged in such research in our universities and elsewhere. It is no appeal for charity or benevolence. It is an appeal to self-interest, to insurance of every business and industry of its own future. That appeal has been met generously by some of our largest industries; it is under consideration by others; it has been refused by one or two largely because they have not grasped the essential difference between the applied-science investigations upon which they are themselves engaged and the pure science which must be the foundation of their own future inventions. A nation with an output of fifty billion annually in commodities which could not be produced but for the discoveries of pure science could well afford, it would seem, to put back a hundredth of one per cent as an assurance of further progress.

Nor is the interest of a particular industry confined to the science research which appears on its face to be directly in the line of that industry. Practically all industry and all business gains by scientific discovery in any direction. The discoveries which led to the invention of the internal-combustion engine and thus to the automobile have benefited every industry and every business in the United States. Business and industry have an interest in the common pool of scientific research irrespective of its particular field. Those fundamental discoveries of the germ basis of disease, with the load of mortality they have lifted from the race, have lowered the rates of insurance and thus contributed directly to business.

From benevolence we have had the generous support of some individuals to our universities and scientific institutions, but this benevolence has come from dishearteningly meager numbers, as witness the discouraging results of recent appeals from the Smithsonian—the father of American science—and the failure of appeals from some of our universities. In a nation of such high appreciation of the value of knowledge, and of such superabundance of private wealth, we can surely hope for that wider understanding which is the basis of constructive action.

NO GREATER CHALLENGE SINCE WORLD WAR THAN THAT OF SCIENTIFIC MEN IN THEIR DEMAND FOR GREATER FACILITIES

And there is something beyond monetary returns in all this. The progress of civilization, as all clear-thinking historians recognize, depends in large degree upon "the increase and diffusion of knowledge among men." Our nation must recognize that its future is not merely a question of applying present-day science to the development of our industries, or to reducing the cost of living, or to eradicating disease and multiplying our harvests, or even to increasing the general diffusion of knowledge. We must add to knowledge both for the intellectual and spiritual satisfaction that comes from widening the range of human understanding, and for the direct practical utilization of these fundamental discoveries. If we would command the advance of our material and, to a considerable degree, of our spiritual life, we must maintain this earnest and organized search for truth. I could base this appeal wholly upon moral and spiritual grounds: the unfolding of beauty, the aspiration after knowledge, the ever-widening penetration into the unknown, the discovery of truth, and finally, as Huxley says, "the inculcation of veracity of thought."

No greater challenge has been given to the American people since the Great War than that of our scientific men in the demand for greater facilities. It is an opportunity to again demonstrate in our Government, our business, and our private citizens the recognition of a responsibility to our people and the nation greater than that involved in the production of goods or in trading in the market.

A Research in the Elements of Metal Cutting

Confined to Tool Sharpness, Tool Form, Chip Dimensions, and the Force Involved

By ORLAN W. BOSTON,[1] ANN ARBOR, MICH.

This paper gives an account of an investigation in the fundamental elements of metal cutting conducted in the Machine Tool Laboratory of the University of Michigan. The object of the investigation was to determine a relation between the force on the tool in the direction of cut for a constant cutting speed of 20 ft. per min., and the degrees of tool sharpness, the various tool angles, the width and depth of cut, and the physical properties of the materials cut. Nine representative types of material were cut, including three carbon steels, three alloy steels, brass, and annealed and unannealed cast iron. The cutting was confined to straight-line motion on a planer and the tools used were of the end-cutting type. No cutting fluids were used, and but one element was varied at a time.

The results show that the clearance angle has no influence on the force on the tool so long as the tool does not drag on the work, that the force on the tool remains constant for a wide variation of keenness of cutting edge and that for thick chips, particularly, the tool edge may be rounded to 1/64-in. diameter without appreciable increase in the cutting force. It is also shown that the cutting force on the tool is reduced in direct proportion to the increase in front-rake angle, all other factors remaining constant; that thick chips are removed more efficiently than thin chips; and that narrow chips are removed more efficiently than wide chips. The results also indicate that there is an apparent relation between some of the physical properties of the metals and their machinability or the cutting force on the tool for the carbon steels in one group, the alloy steels in a second group, and cast iron in a third group.

The complete paper, of which the results only are summarized in the following abridgment, also compares them, problem by problem, with those previously obtained by other investigators, and in addition includes a very complete bibliography of research in cutting tools and metal cutting comprising 129 references.

DURING the last three years an investigation has been conducted as a project of the Department of Engineering Research in the Machine Tool Laboratory of the University of Michigan on elementary principles involved in the cutting of metals.

At the begining it was decided that the experiments should be confined to an investigation of a basic, scientific, rather than a practical, applied, nature. It was felt that the influence of curvature of the surface cut should be eliminated by confining the cuts to straight lines; also that each cut should be of sufficient length to permit the conditions of cutting to become uniform at the instant the reading was taken. In order to secure a straight-line cut having a constant cutting speed throughout the stroke, a planer was selected as the machine tool on which the work would be done.

The problems undertaken were as follows:

a To determine the influence of the degree of sharpness of the cutting edge of the tool, as the only variable, on the force on the tool or the energy required to remove a given volume of metal

b To determine the influence of the clearance back of the cutting edge of the tool, as the variable, on the force on the tool or the energy required to remove a given volume of metal

c To determine the influence of the front rake of the tool, as the variable, on the force on the tool or the energy required to remove a given volume of metal

d To determine the influence of side rake (skew), as the variable, on the force on the tool or the energy required to remove a given volume of metal

e To determine the influence of the depth of cut or width of cut, as the variable, on the force on the tool or the energy required to remove a given volume of metal

f To find a relation between the force on a tool of a given shape required to remove a specific chip of a given material, and its physical or chemical properties.

The Tools

All tools used in these tests were of the cut-off or end-cutting type. They were prepared for each problem in groups identical as to geometric form, heat treatment, grinding, etc., except for the single variable under consideration. They were all machined or forged from carbon or high-speed-steel bars $2^1/_8$ by $1^1/_4$ in. in cross-section and about 12 in. long. Fig. 1 is presented to illustrate the terms used for the parts and angles of the tools and the size of the chip. At *A* is shown a front and side view of a front-rake tool. The front-rake angle is the angle between the tool face and the vertical plane *A-A*. F. W. Taylor called this angle the back slope. The clearance is the angle between the body of the tool back of the

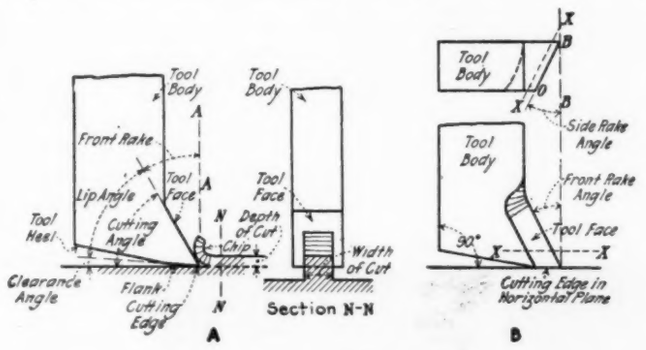

FIG. 1 TOOL PARTS AND ANGLES

cutting edge, or flank, and the work. The cutting angle is the sum of the lip and clearance angles. At *B* is shown a tool which has both front and side rake. The cutting edge is in a horizontal plane. The side-rake angle is best shown in the plan view as the angle between the cutting edge *BO* and the vertical line *BB*. It may also be measured in any plane *X-X* perpendicular to the paper.

The tools were hardened and drawn in accordance with the specifications received from the manufacturer of the steel. Endurance was not an essential feature of the test. It was, however, necessary that a tool retain its geometric form with very little variation throughout a test. Usually the test was not of sufficient length to cause failure of the tool. Some of the tools were hardened in a forge fire and others in gas-fired furnaces, the temperatures of which were definitely determined by thermocouples. Our results show that the furnace-heat-treated tools give more consistent results than those treated in the forge fire.

Method of Measuring Forces

The tests were conducted on a Liberty 30-in. by 36-in. by 8-ft. planer. The power was furnished from a main driveshaft, a satisfactory arrangement in that the horsepower output of the machine was measured rather than the input. The cutting tool was mounted in the standard head on the cross-rail. A specially designed dynamometer was mounted on the planer table. The material being cut was clamped on the bed of the dynamometer.

Fig. 2 shows a line diagram of the dynamometer which consists essentially of a cast-iron bed *B* weighing about 1300 lb., mounted on seven horizontal knife edges *C*. The table is prevented from moving sideways by the four horizontal floating pins shown in the plan view which are supported by the brackets *F*. The bed is prevented from being lifted by four knife edges shown at *G*. An initial load of 2000 lb. tending to force the bed to the left was put on the bed by compresssing the loop spring *D*. This loop spring was made of $^3/_8$-in. square spring steel having major and minor axes to center of bar of

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[1] Associate-Professor of Shop Practice and Director Engineering Shops, University of Michigan. Mem. A.S.M.E.

Contributed by the Machine Shop Practice Division and the Research Sub-Committee on Cutting and Forming of Metals and presented at the Annual Meeting, New York, December 6 to 9, 1926, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Greatly abridged.

11½ and 4¾ in., respectively, and had previously been calibrated on a Riehlé testing machine. It was found to give more satisfactory results than helical springs, as identical load-strain curves were obtained for increasing or reducing increments of load. Fig. 3

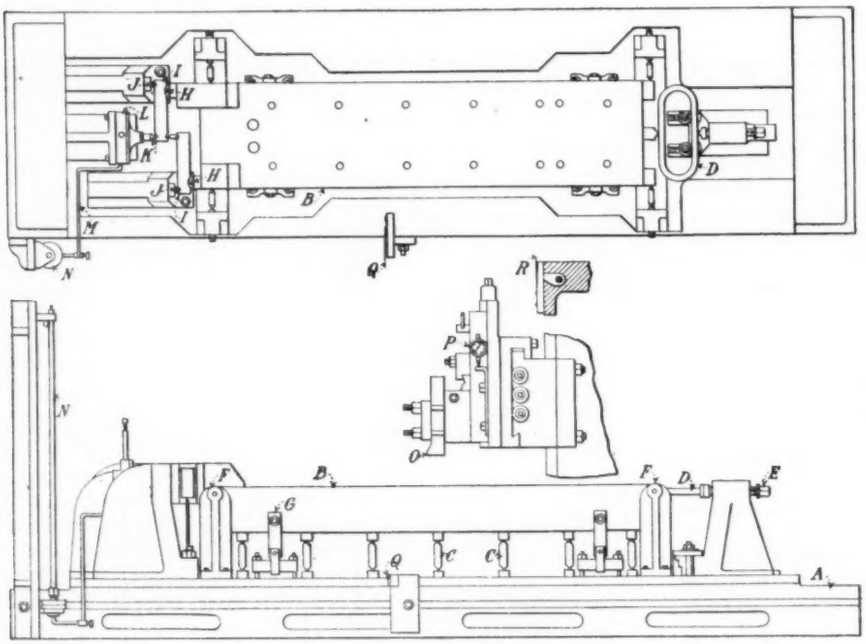


FIG 2 LINE DIAGRAM OF DYNAMOMETER

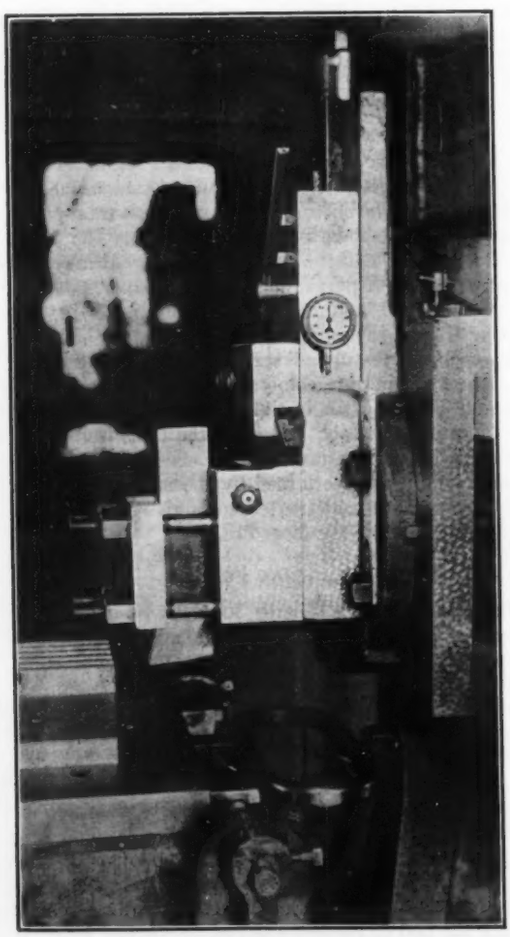


FIG. 3 PLANER TOOL HEAD AND LOOP SPRING
(Also shows indicator for measuring depth of cut.)

shows a close view of the loop spring in its position between the tail casting and the dynamometer bed. Its calibration curve up to 7000 lb. gives consistent values of 0.0314 in. deflection per 1000 lb. of load.

Fig. 4 shows a separate view of the differential mercury-column gage. The point of zero reading on the mercury column corresponded with the initial spring load of 2000 lb. on the dynamometer bed.

The scale on the mercury column was made up by marking the mercury level for each successive load on the dynamometer bed as obtained by compressing the loop spring a definite amount with the adjustable screw *E*, Fig. 2. A 1000-lb. load on the spring produced a 2.539-in. rise of mercury in the column. While the dynamometer was designed for a load of 14,000 lb., it was calibrated only to 7000 lb.

In order that all readings might be taken in the same position of the bed, a spring contact was prepared, half of which was mounted on the vertical column as shown at *R* in the plan view of Fig. 2, the other half mounted on the bed of the planer shown at *Q*. As these springs passed, there was a snap, at which time the reading of the mercury column was taken. Originally all cuts were made 4 ft. in length. It was found, however, that consistent readings could be obtained with a length of cut of 30 to 36 in.

The dynamometer is sensitive to a force of ten pounds which may be read on the mercury-column gage.

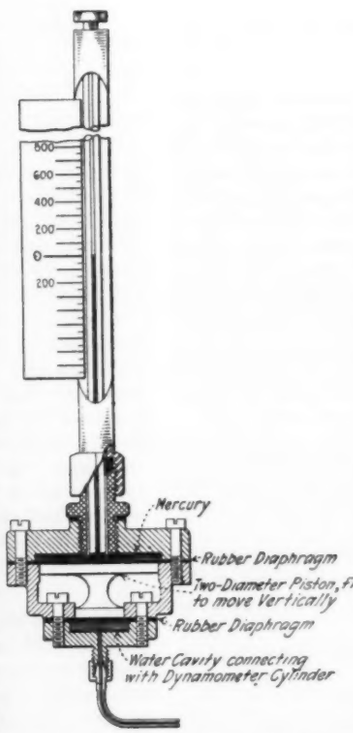


FIG. 4 DIFFERENTIAL COLUMN GAGE

THE MATERIAL

The materials selected to be cut in the experiments were confined to those in most common use which would give a wide range of physical characteristics. They included straight carbon steels (low, medium, and high carbon), 3½ per cent nickel steels of high and low carbon, nickel-chromium steel, cast iron, and brass.

The steel was furnished in bars 4 in. by 6 in. by 48 in. long, prepared for the experiments by milling parallel grooves ⅜ to ½ in. wide and 1 in. deep in the upper surface, lengthwise of the bar. The material left between these grooves formed lands, the widths of which were equal to the width of chip to be cut. The tool was set over one land as shown in Fig. 3, and each successive cut was taken by feeding the tool vertically downward. The feed of the tool was accurately measured on the dial gage mounted on the tool holder as shown in the same figure.

The cast-iron bars were all cast from one ladle in the foundry laboratory in order to get bars as nearly alike as possible. Six bars were cast in a mold, each bar being 1¾ in. wide by 4 in. deep and 48 in. long. The lands were prepared on the top of the bar by milling.

Brass was furnished in rolled sheets, half-hard, of various thicknesses so that when cut on the edge the thickness of the sheet represented the width of the chip. The 1-in.-thick brass sheet was milled on its upper edge so as to present lands of desired widths. This also removed the cold-rolled skin from the side of the land.

Table 1 shows a list of the materials, giving their physical and chemical properties. Table 2 is a summary sheet showing the cutting force for various tools for each material. These tables are referred to later in connection with individual problems.

THE TESTS AND RESULTS

For clarity each problem is treated below individually.

Sharpness of Tool—Problem (a)

Problem (*a*) is "the determination of the influence of the degree of sharpness of the cutting edge of the tool, as the only variable, on the force on the tool or the energy required to remove a given volume of metal." This problem may also be to determine a standard practical degree of tool sharpness. It is divided into two parts. It was necessary to make sure that the tools as ordinarily heat-treated and ground would present a cutting edge which would give uniform results throughout any given test. For this purpose, tools having 0-, 10-, 20-, 30-, and 40-deg. front-rake angles with a clearance angle of 6 deg. were prepared, hardened, and drawn in accordance with the specifications of the manufacturer of the tool steel, some in a forge fire and others in a furnace. Cuts 0.005, 0.020, and

TABLE 1 PHYSICAL AND CHEMICAL PROPERTIES OF MATERIALS CUT

Physical strengths given in lb. per sq. in.

Material	Bar No.	Tension: Elastic limit	Tension: Ultimate strength[1]	Tension: Reduction of area, per cent	Tension: Elongation, per cent 2 in. g.l.	Tension: Type of failure	Compression: Elastic limit	Compression: Ultimate strength[1]	Compression: Type of failure	Shear: Ultimate strength[1]	Hardness: Brinell	Hardness: Sclero-scope	Hardness: Rock-well
S.A.E. 3120	31	47,500	77,000	70.2	30.3	cup and cone	41,700	116,750	.....	54,150	155	24	48
S.A.E. 2345	29	60,000	99,670	42.7	25	cup and cone and plane ⊥ to axis	51,550	140,500	.....	61,650	191	26	59
S.A.E. 2320	30	55,250	79,500	55.6	30	cup and cone and 45° shear	42,750	119,000	.....	54,460	162	24	55
S.A.E. 1035	28	19,900	54,000	60	35	.....	16,000	93,000	.....	37,700	99	19	48
0.15% C	1	25,300	52,400	67	41	cup and cone	22,000	80,500	.....	39,400	106	21	54
0.15% C	2	24,500	52,000	66	41	cup and cone	.....	.....	.....	39,400	102	22	56
0.15% C	3	23,000	51,300	67	40	cup and cone	.....	.....	.....	39,400	101	21	58
0.15% C	4	20,900	52,000	65	40	cup and cone	.....	.....	.....	39,400	102	21	45
0.15% C	5	22,400	50,300	63	42	cup and cone	19,075	85,350	.....	39,410	101	26	56
0.15% C	6	22,500	52,750	63	40	cup and cone	.....	.....	.....	39,400	99	21	56
1.03% C	32	39,170	80,000	56.7	32	cup and cone and plane ⊥ to axis	42,000	112,000	.....	52,670	155	25	52
C. I.	1	none	16,160	none	none	plane ⊥ to axis	none	62,600	pl. 40° to axis	26,960	137	28	70
C. I.	2	none	18,200	none	none	plane ⊥ to axis	none	69,300	pl. 33° to axis	26,000	156	28	83
C. I.	3	none	17,200	none	none	plane ⊥ to axis	none	70,000	pl. 34° to axis	24,000	146	30	76
C. I.	3A	none	14,000	none	none	.....	none	57,200	pl. 34° to axis	24,700	118	25	65
C. I.	4	none	16,800	none	none	plane ⊥ to axis	none	72,000	pl. 25° to axis	23,800	143	30	76
C. I.	4A	none	14,600	none	none	.....	none	59,100	pl. 25° to axis	20,500	143	22	64
C. I.	5	none	17,300	none	none	plane ⊥ to axis	none	64,900	pl. 32° to axis	27,000	153	31	78
C. I.	6	none	16,700	none	none	plane ⊥ to axis	none	65,700	pl. 32° to axis	28,400	154	32	....
C. I.	7A	none	14,520	none	none	plane ⊥ to axis	none	59,780	pl. 37° to axis	21,200	118	22	65
C. I.	8	none	17,200	none	none	plane ⊥ to axis	none	73,000	pl. 33° to axis	22,700	149	31	85
C. I.	8A	none	16,900	none	none	plane ⊥ to axis	none	68,600	pl. 34° to axis	19,100	109	22	57
C. I.	9	none	21,300	none	none	plane ⊥ to axis	none	80,300	pl. 27° to axis	28,300	179	32	88
C. I.	9A	none	13,400	none	none	plane ⊥ to axis	none	60,200	pl. 35° to axis	24,400	121	24	62
C. I.	10	none	.....	none	none	.....	none	.....	.....	.....	....	....	....
C. I.	11	none	18,900	none	none	plane ⊥ to axis	none	77,000	pl. 33° to axis	25,000	121	26	75
Brass	24	....	58,000	43	28	plane 45°	.....	.....	.....	35,600	124	24	70
Brass	25	....	60,700	48	34	plane 45°	.....	.....	.....	34,600	116	20	65
Brass	26	35,000	58,600	32	31	plane 45°	.....	.....	.....	35,600	124	24	70
Brass	27	49,700	58,548	51	..	plane 45°	.....	.....	.....	35,903	121	21	72
Brass	33	25,500	44,877	36	..	plane 45°	.....	.....	.....	28,360	107	17	50
Brass	34	57,300	59,831	29	..	plane 45°	.....	.....	.....	36,060	131	24	71

[1] Ultimate strength = maximum load/original area. Brinell Nos. from 3000 kg. load on 10-mm. ball. Rockwell nos. from $\frac{1}{16}$-in. diam. ball.

CHEMICAL ANALYSES

S.A.E. 3120 steel, bar No. 31: C, 0.17; Mn, 0.60; P, 0.014; S, 0.019; Cr, 0.67; Si, 0.31; Ni, 1.28.
S.A.E. 2345 steel, bar No. 29: C, 0.48; Mn, 0.59; P, 0.010; S, 0.024; Ni, 3.47.
S.A.E. 2320 steel, bar No. 30: C, 0.20; Mn, 0.65; P, 0.014; S, 0.018; Ni, 3.37; Si, 0.18.
S.A.E. 1035 steel, bar No. 28: C, 0.21; Mn, 0.27; P, 0.022; S, 0.030; Si, none.
0.15 per cent carbon steel, bars Nos. 1 to 6 incl.: C, 0.15; Mn, 0.24; Si, 0.13; S, 0.029; P, 0.014.
1.03 per cent carbon steel, bar No. 32: C, 1.03; Mn, 0.28; P, 0.017; S, 0.018; Si, 0.18.
Cast iron, all bars: C, 3.52; Si, 2.18; S, 0.108; Mn, 0.69; P, 0.489.
Brass, bars Nos. 24 and 26: Cu, 61.34; Pb, 1.44; Fe, 0.034; Zn, remainder.
Brass, bar No. 25: Cu, 61.48; Pb, 1.615; Fe, 0.069; Zn, remainder.
Brass, bar No. 27: Cu, 60.68; Pb, 1.635; Fe, 0.132; Zn, remainder.
Brass, bar No. 33: Cu, 61.98; Pb, 1.49; Fe, 0.050; Zn, 36.48.
Brass, bar No. 34: Cu, 64.10; Pb, 1.52; Fe, 0.042; Zn, 34.34.

TABLE 2 CUTTING FORCES

Pounds per 0.001 sq. in. of cross-sectional area of cut

Material	Bar No.	Clearance in degrees, 30° front rake, 0° side rake, ⅛″ width of cut, 0.024″ depth of cut: 2	4	6	8	10	Front-rake angle in degrees, 4° clearance, 0° side rake, ⅛″ width, 0.012″ depth of cut: 0	10	20	30	40	Side-rake angle in degrees, 30° front rake, 4° clear., ⅛″ width, 0.012″ depth of cut: 0	10	20	30	Width of cut, 30°-0°-4° tool, 0.012″ depth of cut: ⅛″	¼″	½″	¾″	Depth of cut in inches, 30°-0°-4° tool, ½″ width: .003	.006	.012	.024	.032	.048
S.A.E. 3120	31	....	....	....	....	....	none	294	255	218	180	218	216	222	226	197	209	218	....	331	265	218	192	184*	172
S.A.E. 2345	29	....	....	....	....	....	none	314	293	275	247	255	265	—	—	225	246	275	....	385	307	275	214	203	....
S.A.E. 2320	30	....	....	....	....	....	none	295	260	229	195	229	241	244	254	195	210	229	....	348	276	229	191	184	....
S.A.E. 1035	28	....	....	....	....	....	none	296	245	214	172	214	—	220	216	210	....	214	217	—	253	214	180	....	....
0.15% C	1	....	....	....	207	219	....	....	....	....	....	246*	....	....	....	231*	244	246*	....	....	288*	246*	212*	199	....
0.15% C	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	220	....	....	....	....	none	....	....	....
0.15% C	3	....	....	206	....	....	....	332	275	233	191	233	....	....	....	....	222*	233	....	....	283	233	208	....	....
0.15% C	4	209	207	....	....	....	....	307	—	234*	....	234*	....	....	....	206	—	234*	....	349	279	234	207	....	....
0.15% C	5	....	....	....	....	....	....	....	....	237*	....	237*	....	....	....	217	226	237*	252	....	292	237*	207	....	....
0.15% C	6	....	....	....	....	....	....	....	....	246	....	246	....	....	246	....	230	246	....	....	307	246	212	....	....
1.03% C	32	....	....	....	....	....	....	414	364	305	262	313	305	314	297	271	285	305	....	444	368	313	256	234	....
C. I.	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	125	98	....	....	....
C. I.	2	....	....	....	....	....	....	....	....	122	....	122	131	128	120	....	....	122	....	....	....	122	....	....	....
C. I.	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	none	83	....	....
C. I.	3A	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	none	72	....	....
C. I.	4	86	84	91	89	90	....	....	....	....	....	....	....	....	....	....	....	....	....	....	135	none	84	....	....
C. I.	4A	....	....	....	....	....	....	....	....	91*	....	91*	....	....	....	....	....	91*	....	....	115	91*	73	....	59
C. I.	5	....	....	....	....	....	....	164	129*	111	99.6	111	....	....	....	....	....	111	....	....	141	111	....	....	....
C. I.	6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	125	none	82	....	....
C. I.	7A	....	....	....	....	....	....	129	....	....	86	....	....	....	....	....	91	86	94	....	....	86	....	....	....
		10° front rake tool																							
C. I.	8	125	125	125	130	127	....	....	....	103*	....	103*	....	....	....	....	....	103*	....	....	127	103*	82	....	65
C. I.	8A	....	....	....	....	....	....	....	....	90*	....	90*	....	....	....	....	....	90*	....	....	108	90*	74	....	60
C. I.	9	....	....	....	....	....	152	134	112	95	86	95	....	....	....	....	....	95	....	....	125	95	....	....	....
C. I.	9A	....	....	....	....	....	127	116	101	88	75	88	....	....	....	....	....	88	....	....	106	88	....	....	....
												0° front rake													
C. I.	10	....	....	....	....	..	143	....	....	....	....	143	145	142	147	....	....	....	....	....	....	....	....	....	....
C. I.	11	....	....	....	....	....	171	....	....	102	....	102	....	....	....	....	97.5	102	103	....	....	102	....	....	....
		0° front rake 0.012 in. deep																							
Brass	24	127	126	126	....	126	126	109	92	79	....	79	....	....	....	....	....	79	....	....	86	79	74	....	....
Brass	25	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	81	76	74	....	....
Brass	26	....	....	....	....	....	125	....	....	74	....	74	74	82	82.5	..	....	74	....	....	....	74	....	....	....
Brass	27	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Brass	33	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Brass	34	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

* Value taken from curve. Available data not reliable. All cutting speeds, 20 ft. per min.

0.040 in. in depth, all having a width of 0.500 in., were made in open-hearth 0.15 per cent carbon steel fully annealed. The cutting speed was kept constant at 20 ft. per min.

The procedure was to grind the tool and cut with it under uniform conditions until the edge became dull, and to observe the length of life of the cutting-tool edge which would make no increase in the reading of the force on the tool. It was found that in order to secure a cutting edge which would remain practically constant when cutting

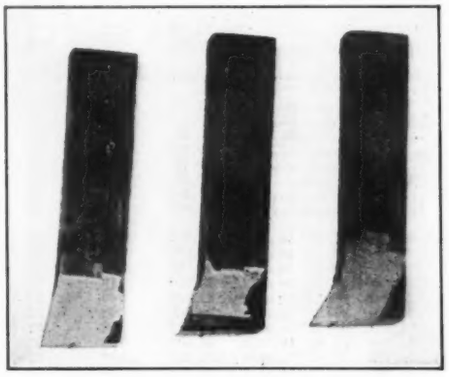


FIG. 5 THREE TOOLS USED IN SHARPNESS TEST, PROBLEM (*a*)
(10-, 20-, and 30-deg. front-rake angles, 4 deg. clearance.)

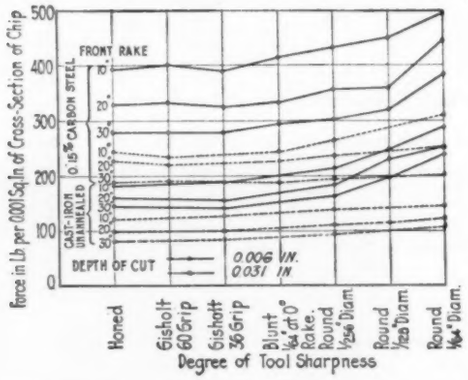


FIG. 6 UNIT-FORCE, TOOL-SHARPNESS CURVES FOR CAST IRON AND STEEL PROBLEM (*a*)
Materials: Cast iron, unannealed, bars Nos. 7 and 10; 0.15 per cent carbon steel, annealed, bars Nos. 3 and 5
Tools: Front rake, 10, 20, and 30 deg.; clearance, 4 deg.
Widths of cut: 0.5 and 0.25 in.
Depths of cut: 0.006 and 0.031 in.
Cutting speed: 20 ft. per min.

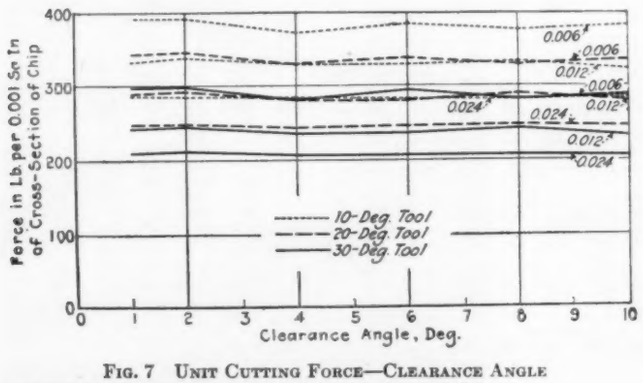


FIG. 7 UNIT CUTTING FORCE—CLEARANCE ANGLE
Material: Open-hearth 0.15 per cent carbon steel, annealed
Tools: 10, 20, and 30 deg. front rake
Speed: 20 ft. per min.

between 400 to 1600 linear feet, the degree of hardness was critical, that is, the temperatures of hardening and drawing must be very carefully controlled. It was also found that a properly hardened tool of either carbon or high-speed steel will present a cutting edge which will take all the cuts necessary for any of the following tests without dulling sufficiently to affect the gage reading.

The second part of the test was to determine the influence of a definite condition of the cutting edge on the force as registered by the dynamometer. The tools used for this test are shown in Fig. 5. Each one has a clearance angle of 4 deg., but front-rake angles of 10, 20, and 30 deg., respectively. They were hardened at 1500 deg. fahr. in water and tempered at 440 deg. fahr. in oil. Brinell and Rockwell hardness numbers taken about the cutting edges were consistent at 652 and 60–62, respectively, for all tools. The cutting speed was 20 ft. per min. in all cases.

The results of the tool-sharpness tests are shown plotted in Fig. 6. The results for both cast iron and low-carbon steel are given for the three tools for each condition of the cutting edge. The solid lines represent the unit forces for the thin chips (0.006 in.). It is seen that the curves remain practically horizontal until the cutting edge is deliberately rounded to $^1/_{256}$ in. diameter when there is a slight increase. Beyond this point the increase in the unit force is more noticeable. For a degree of roundness of the cutting edge of $^1/_{128}$ in. diameter the increase does not seem to be as much as would be expected. While the values for cast iron are much lower on the scale than those for steel, there is a noticeable similarity in the results. The dashed lines are for the heavy chips (0.031 in. deep) and with the exception of the rounded edge of $^1/_{64}$ in. diameter of the 10-deg. front-rake tool cutting steel, there appears to be no appreciable increase in the force on the tool. It was concluded from these curves that for a tool carefully heat-treated and ground on any standard commercial abrasive wheel, there is no need to introduce a correction factor for the force on the tool for various degrees of sharpness or for reasonable wear during the test.

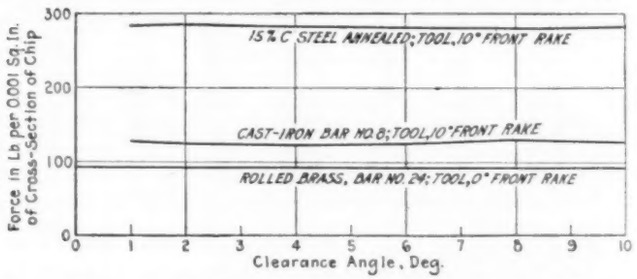

Force in Lb per 0.001 Sq.In. of Cross-Section of Chip
15% C STEEL ANNEALED; TOOL, 10° FRONT RAKE
CAST-IRON BAR NO. 8; TOOL, 10° FRONT RAKE
ROLLED BRASS, BAR NO. 24; TOOL, 0° FRONT RAKE
Clearance Angle, Deg.

FIG. 8 SUMMARY UNIT CUTTING FORCE—CLEARANCE-ANGLE CURVES, PROBLEM (*b*)
Materials: 0.15 per cent carbon steel, cast iron, and brass
Depth of cuts: 0.024 in. Width of cuts: 0.5 in. Speed: 20 ft. per min.

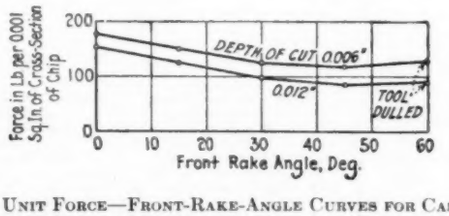


FIG. 9 UNIT FORCE—FRONT-RAKE-ANGLE CURVES FOR CAST IRON
Material: Cast iron, unannealed, bar No. 1
Tools: 4 deg. clearance
Width of cut: 0.5 in.
Speed: 20 ft. per min.

Tool Clearance—Problem (b)

Problem (*b*) is "to determine the influence of the clearance back of the cutting edge of the tool, as the variable, on the force on the tool or the energy required to remove a given volume of metal." A number of tools were prepared having 0-, 10-, 20-, 30-, and 40-deg. front-rake angles, respectively, each in turn ground with clearance angles of 0, 2, 4, 6, 8, and 10 deg. The material cut for this problem was confined at first to the low-carbon steel fully annealed so that the results obtained would be based on a material uniform throughout. The width of the cut in all cases was 0.500 in., the depth of cut was successively 0.003, 0.006, 0.012, and 0.024 in. The cutting speed in all cases was constant at 20 ft. per min. For comparative purposes, the force registered by the dynamometer was reduced to pounds per 0.001 sq. in. of cross-sectional area of the chip.

Representative values for the 10-, 20-, and 30-deg. front-rake tools cutting chips 0.006, 0.012, and 0.024 in. in depth on the low-

carbon steel are shown in Fig. 7. While these curves are drawn through the actual values obtained, it appears obvious that their general tendency is to be straight horizontal lines.

Fig. 8 is a summary sheet showing the unit forces plotted against clearance angles for steel, cast iron, and brass with tools having 10, 10, and 0 deg. front rake, respectively. The depth of cut in each case is 0.024 in. The values given in Table 2, unless noted to the contrary, are for a 30-deg. front-rake tool.

Conclusions may be drawn from the above representative data to the effect that a variation of the clearance angle has no influence on the force required to remove the chip. Abrasion on the flank of the tool would probably prove excessive for low clearance angles, yet the less the clearance angle, the more the cutting edge is supported and the more metal there is to carry away the heat generated. As the feed, such as that given a side-cutting tool, does not enter into the work of these tests and as all tools are machine-ground, a clearance angle of 4 deg. was approved as practicable for the tools used in the remainder of the work.

Front-Rake Angle—Problem (c)

Problem (*c*) is "to determine the influence of the front rake of the tool, as the variable, on the force on the tool or the energy required to remove a given volume of metal." The 12 tools prepared for the front-rake investigation all have clearance angles of 4 deg. and front-rake angles of 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60, and 75 deg., respectively. The data from these experiments have, for comparative purposes, also been reduced to the force in pounds per 0.001 sq. in. of cross-sectional area of the chip. The cutting speed in all cases has been confined to 20 ft. per minute, the width of cut to 0.50 in., the tool clearance to 4 deg., and the chip thicknesses to 0.006, 0.012, and 0.024 in., respectively.

In Fig. 9, some results are shown with the 60-deg. front-rake tool. It is to be noted, however, that the results for the 60-deg. front-rake angle are slightly higher than those for the 45-deg. angle. The results shown add weight to the evidence that beyond a certain front-rake angle there is no further reduction in the force on the tool.

Fig. 10 is a summary sheet showing the influence of the front-rake angle on the unit force for all materials cut with a depth of cut of 0.012 in. It is quite obvious from these results that the relation follows the straight-line law and the force on the tool is reduced as the front-rake angle is increased, till a certain limiting angle is reached. Beyond this angle, which seems to be between 20 and 30 deg. for brass, 25 to 30 deg. for cast iron, and above 45 deg. for steel, the influence of the front rake is less pronounced. Some metals are more readily influenced by the front rake than others.

Side-Rake Angle—Problem (d)

Problem (*d*) is "to determine the influence of side rake (skew), as the variable, on the force on the tool or the energy required to remove a given volume of metal." The first set of tools used were all of 30 deg. front rake and 4 deg. clearance, but had side-rake angles of 0, 10, 20, and 30 deg., respectively. The clearance was measured in the direction of travel of the tool.

A second set of side-rake tools, each having 0 deg. front rake and 0, 10, 20, 30, 45, 60, 75 deg. side rake, respectively, was later used. With these tools the clearance angle was ground at right angles to the cutting edge. The 30-deg. and 75-deg. side-rake tools, however, were later ground, so that the clearance was measured from the cutting edge in the direction of tool travel for check purposes, as discussed later.

Fig. 11 is a summary sheet showing the values of the unit forces for the 30-deg. front-rake tools having 0, 10, 20, and 30 deg. side rake for eight different materials. The width of cut in each case was 0.500 in., and the depth of cut 0.012 in., so that all values in the figure are directly comparable.

All of the results which are available for the first set of tools indicate that the value of the side-rake angle has very little influence on the unit or total force on the tool in removing a given chip.

Because of the small cutting angles of these tools and the tendency of such angles to fail, dig in, or otherwise cause trouble, the side-rake angle of the first set of tools was not carried beyond 30 deg. The values obtained, however, would indicate that all of these curves would continue to be straight horizontal lines for side-rake angles greater than 30 deg. In order, however, to make sure of this point and to obtain comparable data with another front-rake-angle tool, a second series of side-rake tools having 0-deg. front rake was prepared.

Fig. 12 shows the results of the force in pounds per 0.001 sq. in. cross-sectional area of chip as a function of the side-rake angle for this set of tools when cutting brass, bar No. 27. Fig. 13 shows the

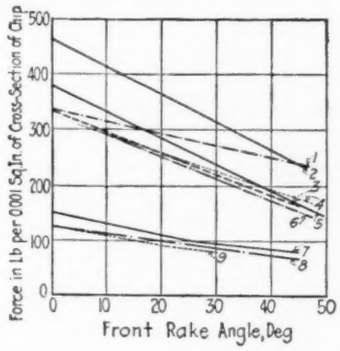


FIG. 10 SUMMARY UNIT FORCE—FRONT-RAKE-ANGLE CURVES

Tools: 4 deg. clearance. Depth of cut: 0.012 in. Width of cut: 0.5 in. Speed: 20 ft. per min.
Curve 1: S.A.E. 2345 steel, bar No. 29
Curve 2: 1.03 per cent carbon steel, annealed, bar No. 32
Curve 3: S.A.E. 3120 steel, bar No. 31
Curve 4: S.A.E. 2320 steel, bar No. 30
Curve 5: 0.15 per cent carbon steel, annealed, bar No. 3
Curve 6: S.A.E. 1035 steel, bar No. 28
Curve 7: Cast iron, unannealed, bar No. 9
Curve 8: Cast iron, annealed, bar No. 9A
Curve 9: Brass, bar No. 24

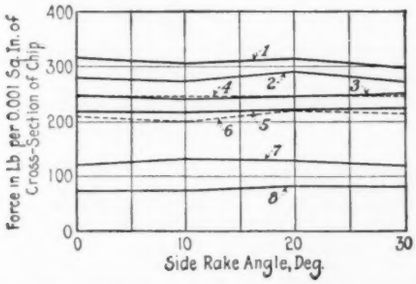


FIG. 11 SUMMARY UNIT FORCE—SIDE-RAKE-ANGLE CURVES, PROBLEM (*d*)

Tools: 4 deg. clearance, 30 deg. front-rake
Depth of cut: 0.012 in. Width of cut: 0.5 in. Speed: 20 ft. per min.
Curve 1: 1.03 per cent carbon steel, annealed, bar No. 32
Curve 2: S.A.E. 2345 steel, bar No. 29
Curve 3: S.A.E. 2320 steel, bar No. 30
Curve 4: 0.15 per cent carbon steel, annealed, bar No. 6
Curve 5: S.A.E. 3120 steel, bar No. 31
Curve 6: S.A.E. 1035 steel, bar No. 28
Curve 7: Cast iron, unannealed, bar No. 2
Curve 8: Brass, rolled, bar No. 26

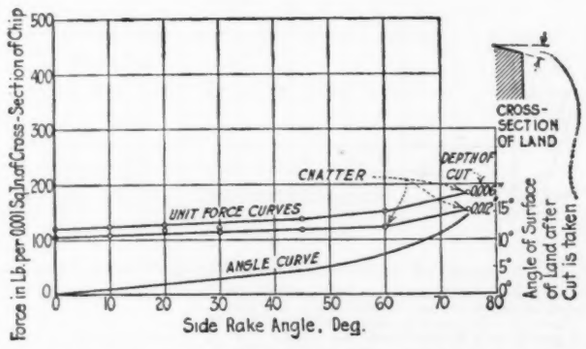


FIG. 12 UNIT FORCE—SIDE-RAKE-ANGLE CURVES FOR BRASS, EXPERIMENT NO. 57

Material: Brass, bar No. 27
Tools: 4 deg. clearance, 0 deg. front-rake
Width of cut: 0.312 in. Speed: 20 ft. per min.

unit-force curves as a function of the side-rake angle of the 0-deg. front-rake tools for cast iron, S.A.E. 2320 steel, and 0.15 per cent carbon steel.

The values obtained for both sets of side-rake tools for the various metals cut seem to indicate decisively that for moderate values the side-rake angle, all other factors remaining constant, has no in-

fluence on the total or unit force on the tool. When the side-rake angle reaches 60 deg., however, a definite increase is noted, and for greater values of side rake the force is markedly increased.

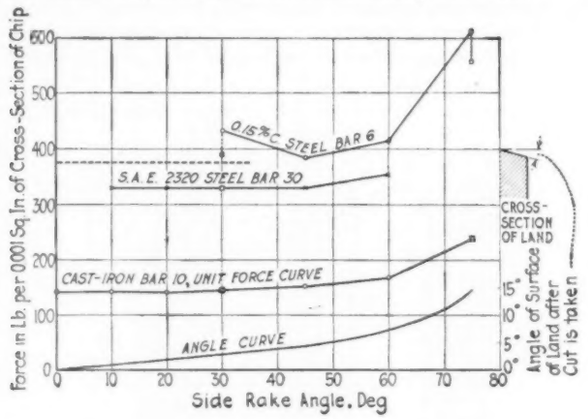

Force in Lb. per 0.001 Sq. In. of Cross-Section of Chip
0.15% C STEEL BAR 6
S.A.E. 2320 STEEL BAR 30
CROSS-SECTION OF LAND
CAST-IRON BAR 10, UNIT FORCE CURVE
ANGLE CURVE
Angle of Surface of Land after Cut is taken
Side Rake Angle, Deg

FIG. 13 UNIT FORCE—SIDE-RAKE-ANGLE CURVES, EXPERIMENT 58
Tools: 4 deg. clearance, 0 deg. front-rake
Width of cut: 0.5 in. Depth of cut: 0.012 in. Speed: 20 ft. per min.

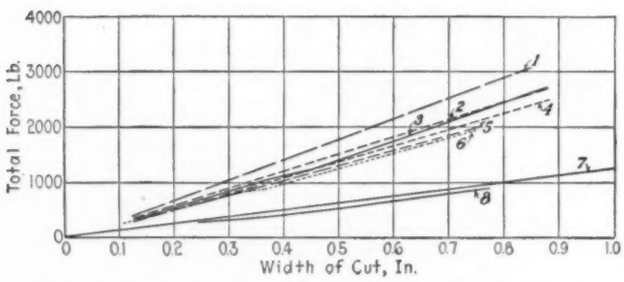


FIG. 14 SUMMARY OF TOTAL FORCE—CHIP-WIDTH CURVES, PROBLEM (e)
Tools: 4 deg. clearance. Depth of cut: 0.012 in. Speed: 20 ft. per min.
Curve 1: 1.03 per cent carbon steel, bar No. 32, front-rake angle 30 deg.
Curve 2: S.A.E. 2345 steel, bar No. 29, front-rake angle 30 deg.
Curve 3: 0.15 per cent carbon steel, bar No. 5, front-rake angle 30 deg.
Curve 4: S.A.E. 2320 steel, bar No. 30, front-rake angle 30 deg.
Curve 5: S.A.E. 3120 steel, bar No. 31, front-rake angle 30 deg.
Curve 6: S.A.E. 1035 steel, bar No. 28, front-rake angle 30 deg.
Curve 7: Brass, bar No. 34, front-rake angle 15 deg.
Curve 8: Cast iron, annealed, bar No. 7A, front-rake angle 30 deg.

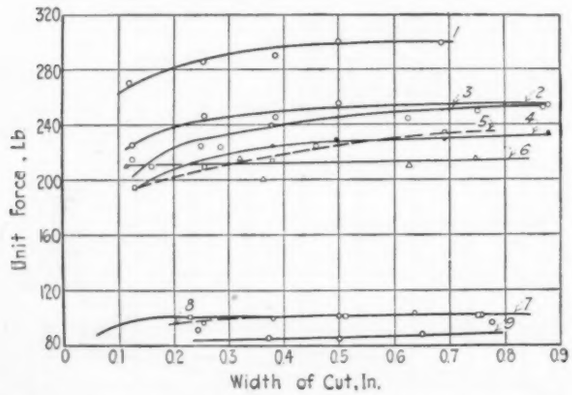


FIG. 15 SUMMARY OF UNIT FORCE—CHIP-WIDTH CURVES, PROBLEM (e)
Tools: 4 deg. clearance; front-rake angle 30 deg. (except brass, 15 deg.)
Depth of cut: 0.012 in. Speed: 20 ft. per min.
Curve 1: 1.03 per cent carbon steel, bar No. 32
Curve 2: S.A.E. 2345 steel, bar No. 29
Curve 3: 0.15 per cent carbon steel, bar No. 5
Curve 4: S.A.E. 2320 steel, bar No. 30
Curve 5: S.A.E. 3120 steel, bar No. 31
Curve 6: S.A.E. 1035 steel, bar No. 28
Curve 7: Brass, rolled, bar No. 33
Curve 8: Cast iron, unannealed, bar No. 11
Curve 9: Cast iron, annealed, bar No. 7A

Force—Chip Width and Depth of Cut, Problem (e)

Problem (e) is "to determine the influence of the depth of cut or width of cut, as the variable, on the force on the tool or the energy required to remove a given volume of metal." In order to have but one variable at a time, the problem has been divided into two parts so as to determine, first, the influence on the force on the tool of a change in width of chip, and, secondly, the influence on the force due to a change in the depth of cut.

Force—Chip Width. The 30-deg. front-rake tool having a 4-deg. clearance angle was found to give consistently reliable results in previous tests on most materials. It was therefore selected as the tool to be used in the chip-width series of tests. For brass, however, in order to avoid chatter, which occurs in taking heavy cuts with small-front-rake-angle tools, and to avoid hogging in, or taking of alternately thick and thin chips, which occurs with tools of excessive front rake such as the 30-deg. front-rake tool, a tool having 15 deg. front rake and 4 deg. clearance was used. A 0-deg. front-rake tool was used with the 30-deg. tool on annealed cast iron and on brass as noted.

The usual cutting speed was 20 ft. per min. This is rather low for cutting brass. A number of check runs were made at 35 ft. per min. for brass as well as some of the steels, and identical results were obtained in every case for the two speeds.

Depths of cut were confined in most instances to 0.006, 0.012, and 0.024 in. The width of cut ranged between $\frac{1}{8}$ in. and 1 in.

Fig. 14 is a summary sheet of total forces for a depth of cut of 0.012 in. for various widths of cut for all of the materials used. A 30-deg. front-rake tool was used in all cases except for curve 7 for brass, for which a 15-deg. front-rake tool was used. The total-force curves, which are concave upward, cause the unit-force curves

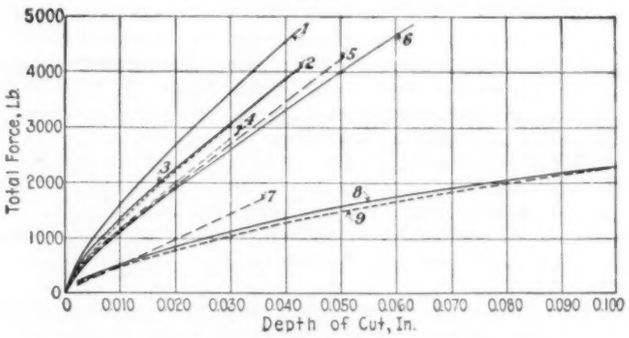


FIG. 16 SUMMARY OF TOTAL FORCE—CHIP-THICKNESS CURVES, PROBLEM (e)
Tools: 4 deg. clearance, 30 deg. front rake (except brass, 15 deg.)
Width of cut: 0.5 in. Speed: 20 ft. per min.
Curve 1: 1.03 per cent carbon steel, bar No. 32
Curve 2: S.A.E. 2345 steel, bar No. 29
Curve 3: 0.15 per cent carbon steel, bar No. 4
Curve 4: S.A.E. 2320 steel, bar No. 30
Curve 5: S.A.E. 3120 steel, bar No. 31
Curve 6: S.A.E. 1035 steel, bar No. 28
Curve 7: Brass, rolled, bar No. 26
Curve 8: Cast iron, unannealed, bar No. 8
Curve 9: Cast iron, annealed, bar No. 8A

to be concave downward and to drop for small widths of cut; also those total-force curves which cross the abscissa axis to the right of the origin cause the unit-force curve to drop for small widths of cut. Fig. 15 is another summary sheet showing the unit forces for the curves of Fig. 14, plotted over the widths of cut as abscissas. All curves except 6 for S.A.E. 1035 steel and 9 for annealed cast iron are shown concave downward for the small widths of cut. Both curves would, however, turn downward if continued to the left. From this evidence it is concluded that the total and unit forces are lower for the narrower width of cut. The unit force increases rapidly with an increase in width of cut for most metals until a width of 0.24 in. is reached, after which the increase is less and in some instances there is no increase.

Force—Depth of Cut. The results of the second part of Problem (e), i.e., to show the influence on the force on the tool due to a change in the depth of cut or chip thickness for a constant width of cut, are given below. Again the 30-deg. front-rake tool having 4 deg. clearance was used for all metals except brass, when the 0-deg. and 15-deg. front-rake tools were used. A 0-deg. tool was used with the 30-deg. front-rake tool on cast iron.

Fig. 16 shows all total-force curves for the 0.5-in. width of cut for the nine different materials cut, plotted on the depths of cut as abscissas. All of the curves are decidedly concave downward, with increased curvature for the thinner chips. Curve 7 for brass is drawn as a straight line, although it is actually very slightly concave downward. A 30-deg. front-rake tool was used in all cases

except for brass, for which a 15-deg. front-rake tool was used. Corresponding values for the unit forces for the various metals cut, plotted on the depths of cut in inches as abscissas, are shown in Fig. 17. These curves show that the unit forces for the very thin chips (0.003 in. and less) are relatively high, but are reduced rapidly with an increase in depth of cut. This reduction in unit force becomes more retarded as the depth of cut is increased, so that for depths of cut of 0.030 in. or greater there appears to be little reduction in unit force for an increase in depth of cut.

Physical Properties of Materials Cut—Problem (f)

Problem (*f*) is "to find the relation between the force on the tool of a given shape required to remove a specific chip of a given material, and the physical or chemical properties of the material." For this purpose, the unit force, that is, the force per 0.001 sq. in. of cross-sectional area of chip for a 30-deg. front-rake tool, has been selected for each material to compare with the other physical properties of the material. The unit force for the 30-deg. tool was selected, as that tool gave satisfactory results for all metals except brass. Even that for brass with the 0.012-in. depth of cut is considered reliable and representative of the properties of the material. All unit forces were determined from a cut 0.5 in. wide and 0.012 in. deep. These unit forces are shown in Fig. 10.

In Fig. 18 several curves are plotted to show any relation which might exist between the unit forces and the other physical properties

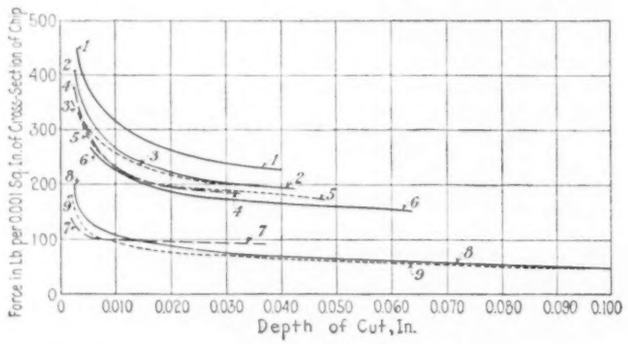


FIG. 17 SUMMARY OF UNIT FORCE—CHIP-THICKNESS CURVES

Tools: 4 deg. clearance, 30 deg. front rake (except brass, 15 deg.)
Width of cut: 0.5 in. Speed: 20 ft. per min.
Material: Curve numbers same as in Fig. 16.

of the materials. The abscissas 1, 2, 3, etc., represent the various materials referred to in the caption of the figure. These materials are representative of all of those cut, and are arranged in order of intensity of unit forces.

Fig. 19 shows the unit force and strength plotted over the materials referred to in the caption of Fig. 18 as abscissas. Figs. 18 and 19 indicate no consistent relation between the physical properties of the various metals and the unit forces. They do suggest, however, the advantage of dividing the materials into four groups, namely, alloy steels, carbon steels, brasses, and cast irons, for further study.

SUMMARY AND CONCLUSIONS

To enable one to compare the results obtained above, three sets of curves have been prepared as a function of cubic inches of metal removed per minute per horsepower. Fig. 20 shows these values for various front-rake angles in degrees as abscissas. For all metals there is a distinct increase in the amount of metal removed per minute per horsepower as the front-rake angle is increased, i.e., as the cutting angle is reduced. For all of these curves the depth of cut is 0.012 in., the width of cut, 0.5 in., and the cutting speed, 20 ft. per min. It is observed from the figure that the 1.03 per cent carbon steel has the least amount of metal removed per horsepower-minute, increasing from 0.94 cu. in. per min. for the 10-deg. front-rake tool to 1.52 cu. in. per min. for a 40-deg. front-rake tool. The unit forces are obtained from Fig. 10 and the cubic inches per minute per horsepower equals 396 divided by the unit force. These curves also show that the influence of the front-rake angle is less for S.A.E. 2345 steel than it is for the 0.15 per cent carbon steel, the latter showing an increase from 1.12 cu. in. per minute per horsepower for a 5-deg. front-rake tool to 2.37 cu. in. for a 45-deg. front-rake tool, while the corresponding figures for S.A.E. 2345 are 1.23 and 1.65 cu. in. The brass and cast iron are shown much higher on the scale than the steels.

Fig. 21 shows the cubic inches of metal removed per minute per horsepower plotted over the width of cut in inches for the various

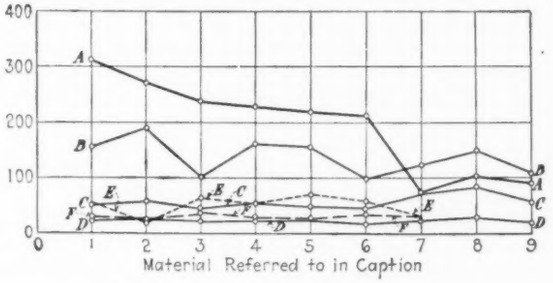


FIG. 18 PHYSICAL-PROPERTY CURVES

CURVES	MATERIALS
A Unit force for 0.5 by 0.012-in. chip 30-deg. front rake tool	1 1.03 per cent carbon steel, bar No. 32
B Brinell hardness number	2 S.A.E. 2345 steel, bar No. 29
C Rockwell hardness number	3 0.15 per cent carbon steel, bar No. 4
D Scleroscope hardness number	4 S.A.E. 2320 steel, bar No. 30
E Percentage reduction of area (tension)	5 S.A.E. 3120 steel, bar No. 31
F Percentage elongation in 2 inches	6 S.A.E. 1035 steel, bar No. 28
	7 Brass, rolled, bar No. 26
	8 Cast iron, unannealed, bar No. 8
	9 Cast iron, annealed, bar No. 8A

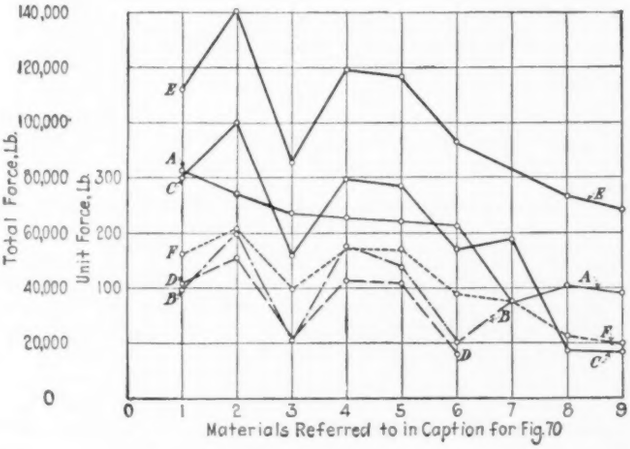


FIG. 19 PHYSICAL-PROPERTY CURVES

(Material numbers same as in Fig. 18.)

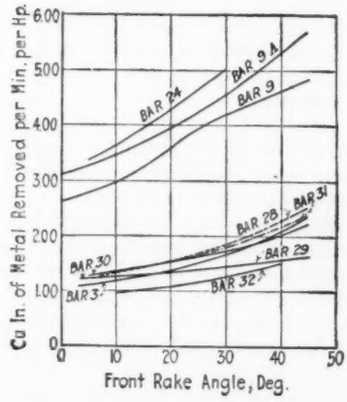


FIG. 20 CUBIC INCHES OF METAL REMOVED PER MINUTE PER HORSEPOWER —CHIP WIDTH

Tools: 4 deg. clearance. Width of cut: 0.5 in. Depth of cut: 0.012 in. Speed: 20 ft. per min.
(Bar No. 9, cast iron, unannealed; bar No. 9A, cast iron, annealed.)

metals for the 30-deg. front-rake tool; for brass a 15-deg. tool was used. These curves fall off slightly for widths of cut between 0.1 and 0.3 in. The values for 0.15 per cent carbon steel (refer to Fig. 15 for unit forces) for a 0.2-in. width of cut is 1.77 cu. in. per minute per horsepower, and for a 0.7-in. width is 1.57 cu. in.; again the 1.03 per cent carbon steel is the lowest of all the curves of the figure, with about 1.5 cu. in. of metal removed per minute per horse-

power for a 0.1-in. width, and 1.32 cu. in. for a 0.7-in. width of cut.

Fig. 22 shows a similar set of curves plotted over the depth of cut in inches for the 30-deg. front-rake tool; for brass a 15-deg. tool was used. In all cases the amount of metal removed in cubic inches increases rapidly until a depth of cut of 0.010 in. is reached and then less rapidly until a depth of cut of about 0.025 in. is reached, after which the increase for the steels is less marked. Again the lowest curve is for the 1.03 per cent carbon steel, which has a value of 1.06 cu. in. removed per minute per horsepower for 0.005-in. depth of cut and increases to 1.25 cu. in. for 0.010-in. depth of cut and to 1.73 cu. in. for 0.040-in. depth of cut. The 0.15 per cent carbon steel increases from 1.15 in. for a 0.0025-in. depth of cut to 1.86 cu. in. for a 0.025-in. depth of cut.

These curves indicate clearly the influence of the variables involved on the cutting efficiency of the tool. For these curves the cubic inches removed per horsepower-minute has been used as the ordinate, but some authors have used the inverse ratio, that is, the horsepower per cubic inch of metal removed per minute. These

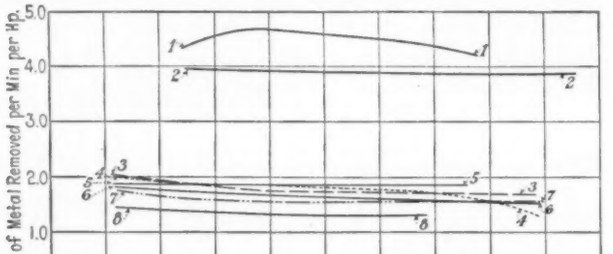


FIG. 21 CUBIC INCHES OF METAL REMOVED PER MINUTE PER HORSEPOWER —CHIP WIDTH

Tools: 4 deg. clearance, 30 deg. front rake (except brass, 15 deg.)
Depth of cut: 0.012 in. Speed: 20 ft. per min.
Curve 1: Cast iron, annealed, bar No. 7A
Curve 2: Brass, bar No. 34
Curve 3: S.A.E. 2320 steel, bar No. 30
Curve 4: S.A.E. 3120 steel, bar No. 31
Curve 5: S.A.E. 1035 steel, bar No. 28
Curve 6: 0.15 per cent carbon steel, bar No. 5
Curve 7: S.A.E. 2345 steel, bar No. 29
Curve 8: 1.03 per cent carbon steel, bar No. 32

values are readily interchangeable, one being the reciprocal of the other.

The following conclusions are based only on the data collected by the author as presented above, and are not influenced by the work of other investigators. They are, however, compared later in the complete paper with the results of others. In reading these conclusions it should be kept in mind that this is an investigation of forces on the tool as a function of some one variable, rather than a study of tool endurance.

1 The burred keenness of a newly ground tool edge disappears after the first two or three feet of cutting. The tool edge maintains this new condition while cutting several hundred feet. When a second change occurs, the failure of the tool soon follows.

2 The force on the tool for a given material and size of cut is the same for a tool carefully heat-treated and ground on any standard commercial abrasive wheel. A tool with a carefully honed cutting edge gives the same force as a tool ground on a coarse-grained wheel; also a slight rounding of the edge with a honing stone causes no increase in the force on the tool, other conditions being constant. The thicker the chip, the blunter the cutting edge may be without producing a noticeable increase in the force on the tool (see Fig. 6).

3 A variation of the clearance angle between 1 and 10 deg. has no influence on the force on the tool in the direction of the cut, all other conditions being constant (see Fig. 8).

4 The force on an end cutting tool for all materials is reduced in direct proportion to the increase of the front-rake angle, until a certain limiting angle is reached. Beyond this limiting angle, which appears to be between 20 and 30 deg. for brass, 25 to 30 deg. for cast iron, and above 45 deg. for steel, the influence of the front-rake angle is less pronounced, i.e., for the same increase in front-rake angle, the unit force is reduced a smaller amount. For front-rake angles above 60 deg., that is, for cutting angles less than 30 deg., the total pressure on the tool in the direction of cut is increased (see Fig. 9). For some materials, however, such as S.A.E. 2345, the force on the tool is influenced less for a given increase in front-rake angle than others (see Fig. 10).

5 The introduction of side rake on an end cutting tool has no influence on the unit or total force on a tool in removing a given chip. For a tool having front and side rake, cleaner cutting was noted than for the 0-deg. front-rake tool with various angles of side rake (see Fig. 11). For values of side rake of 60 deg. or greater on the 0-deg. front-rake tools, an increase in the force on the tool in the direction of cut occurs (see Figs. 12 and 13).

6 For the same material, tool, and depth of cut, the total force on the tool increases with an increase in width of cut, but at a greater rate. The total force on the tool in the direction of the cut plotted over the width of cut gives a curve slightly concave upward, passing through the origin; the curvature increases as the width approaches zero (see Fig. 14). In other words, all other conditions remaining constant, a chip less than 0.25 in. in width is removed more efficiently than a chip wider than 0.25 in. This applies for rectangular chips removed with an end cutting tool (see Fig. 15).

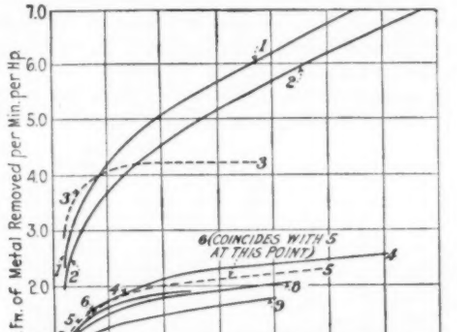


FIG. 22 CUBIC INCHES OF METAL REMOVED PER MINUTE PER HORSEPOWER —DEPTH OF CUT

Tools: 4 deg. clearance, 30 deg. front rake (except brass, 15 deg.)
Width of cut: 0.5 in. Speed: 20 ft. per min.
Curve 1: Cast iron, annealed, bar No. 8 A
Curve 2: Cast iron, unannealed, bar No. 8
Curve 3: Brass, rolled, bar No. 26
Curve 4: S.A.E. 1035 steel, bar No. 28
Curve 5: S.A.E. 3120 steel, bar No. 31
Curve 6: S.A.E. 2320 steel, bar No. 30
Curve 7: 0.15 per cent carbon steel, bar No. 3
Curve 8: S.A.E. 2345 steel, bar No. 29
Curve 9: 1.03 per cent carbon steel, bar No. 32

7 For the same material, tool, and width of cut, all other conditions being constant, the total force on the tool increases as the depth of cut increases, but at a slower rate. The total force on the tool in the direction of cut plotted over the depth of cut gives a curve concave downward and passing through the origin; the curvature increases as the depth approaches zero (see Fig. 16). The force on the tool per 0.001 sq. in. of cross-sectional area of chip is much higher for a thin chip than for a thick chip; this difference is greatest, however, for increments in the small depths of cut. When the depth of cut is in excess of 0.030 in., the unit-force curve becomes almost horizontal. The unit force increases rapidly as the depth of the cut is reduced below 0.030 in. This applies for rectangular chips removed with an end cutting tool (see Fig. 17).

8 When the unit cutting forces are plotted against the various physical properties, no solution is indicated when all metals are taken as a group. For certain physical properties the materials divide themselves into three groups, namely, straight carbon steels, alloy steels, and cast iron, for each of which a relation is indicated. For the straight carbon steels it appears that the elastic limit in tension and compression, the ultimate strength in tension and shear, and the Brinell hardness are functions of the unit force on the tool. For the alloy steels the elastic limit in tension and compression, the ultimate strength in tension, compression, and shear, the Brinell hardness, and the percentage of elongation in two inches, each indicates a relation to the unit force. For cast iron a similar relation is suggested for the ultimate strength in tension, compression, and shear, and the scleroscope hardness number.

Opportunities Afforded the Mechanical Engineer in the Railroad and Railroad-Supply Industries

Progress Report of Sub-Committee on Professional Service, Railroad Division, A.S.M.E.

THE Sub-Committee on Professional Service of the Railroad Division, A.S.M.E., has a number of objects in view in presenting a report showing the progress that has been made toward collecting and assembling information pertaining to the opportunities afforded the mechanical engineer in the railroad and railroad-supply industries. Sufficient facts and data of interest and value to the Society have already been assembled that seem to warrant the presenting of this report. There are additional facts yet to be collected, in which work it is necessary to have the cooperation of both industries. Such coöperation is more easily obtained when all concerned understand how the information the Sub-Committee is asking for is to be used. Furthermore, it is hoped that this progress report will stimulate members of the Society to make suggestions that will be useful to the Sub-Committee in the performance of its work.

The subject "Do the Railroads Want College Men?" has for a number of years been one of considerable interest to railroad men. Many editorial comments, articles, and letters have been published from time to time in the columns of the railway trade press. A study of these articles shows that the majority of the contributors seem to believe that the railroads want college men but are not willing to go after them or to pay salaries commensurate with the education and training that college men receive. The opinion was also generally expressed that few college men are willing to spend the time in subordinate positions to acquire the necessary experience. Most of the opinions were of such a pessimistic nature that it was practically impossible to obtain other than a somewhat gloomy picture of the future for college men in the railroad industry. The Railroad Division, feeling that much of the gloom was unjustified, thought that an investigation such as that being made would be of help in clearing up many misunderstandings.

At the January 29, 1926, meeting of the Executive Committee of the Railroad Division, a communication was read from A. J. Wood, head of the Department of Mechanical Engineering of The Pennsylvania State College, suggesting that a committee be appointed to study the problem of the relation of the various technical schools to the railroad industry and the employment of technical graduates by the various railroad companies.

On March 24, 1926, James O. G. Gibbons, consulting engineer, Newark, N. J., presented a paper on the Opportunities for Engineers in Industry[1] at a joint meeting of the Metropolitan Student Branches with the Metropolitan Section of the A.S.M.E. In this paper Mr. Gibbons pointed out the necessity of advising engineering students and graduates concerning the duties, opportunities, and responsibilities of the engineer, so that they could make a more intelligent choice of their profession. Benefiting by the suggestions in this paper, the Executive Committee was able to formulate definite objectives for the work of such a committee as that proposed by Professor Wood. The work accomplished during the past year has been done under the direction of the Sub-Committee on Research. However, a Sub-Committee on Professional Service has been formed which hopes to present a final report at the Annual Meeting in 1927.

Objects and Scope of Investigation

Realizing that the Class I railroads of the United States (railroads having an operating income above $1,000,000) are the largest employers of labor in any industry; that many mechanical engineers have a pessimistic viewpoint as to the opportunities afforded them in railroad work; that the industry is evidently not getting its proper share of the better mechanical-engineering talent from the technical schools, and that many mechanical engineers eminently fitted for railroad work are entering other fields of endeavor, the Railroad Division is undertaking the collecting and assembling of facts and information with the following objects in view:

1 To assemble facts pertaining to the railroad and railway-supply industries in order to assist the young mechanical engineer to a knowledge of the industry as it affects him personally.

2 To give technical schools and colleges a source of reliable and accurate information with which they can be of service to students contemplating entering railroad or railway supply work.

3 To furnish a source of reliable and accurate information which the Committee on Education and Training for the Industries, the Committee on Relations with the Colleges, and the representatives of the A.S.M.E. coöperating with the Society for the Promotion of Engineering Education may have available when needed.

4 To have available for the members of The American Society of Mechanical Engineers a source of fact information with which the Society as an organization or its individual members can render real service to the young mechanical engineer.

5 To encourage similar studies or activity by other divisions of the A.S.M.E. in their respective fields, if the studies made by the Railroad Division bring satisfactory results.

The scope of the Sub-Committee's work includes both the railroad and railroad-supply industries, the latter being the name generally applied to the industry which manufactures railway equipment and supplies. Approximately 43 per cent of the executive and technical officers and sales staff of railway-supply concerns promoted since December, 1919, have been recruited from the railroads. It is estimated by reputable authorities that for every man in railway service there is another at work making materials the railroads buy. It is then quite natural that the railroad-supply industry should select good men for its executive and sales staffs from the railroads.

Procedure

The Sub-Committee has divided its work into two parts, namely, collecting and assembling facts and information obtained (1) by library search, and (2) by writing to the various railway and railway-supply companies. Facts and information pertaining to the careers of railway executive officers and mechanical engineers have been obtained from the Biographical Directory of Railway Officials, 1922, published by the Simmons-Boardman Publishing Company, and from sketches published in the *Railway Age*, *Railway Review*, and *Railway Mechanical Engineer*. Data pertaining to salaries paid to railway officers have been obtained from the records of the U. S. Senate Committee on Interstate Commerce, and publications of the Interstate Commerce Commission and Bureau of Labor Statistics, U. S. Department of Labor, Statistics concerning other industries have been obtained from the Society for the Promotion of Engineering Education, for the purpose of comparison.

A total of 221 questionnaires were mailed, and replies were received from 64 companies and are still coming in. Practically all the replies are from representative companies and the information they contain affords a very good picture of the situation in both industries as a whole.

Facts Relative to the Railroad Industry—Comparison with Other Industries

There are 1023 railroads in the United States and Canada, about 190 of which are Class I railroads. These latter operate approximately 90 per cent of the total railway mileage in the United States, and earn about 96 per cent of the total revenues. Ac-

[1] See Mechanical Engineering, March, 1926, p. 261.

cording to the *Monthly Labor Review*, published by the U. S. Bureau of Labor Statistics, there were employed on these roads during one week in July, 1926, a total of 1,816,818 men and women. A comparison of this figure with the number employed by other industries during the same period is given in Table 1. The second largest industry according to the number employed, is the iron and steel industry, the textile industry being third.

TABLE 1 COMPARISON OF EMPLOYMENT IN 13 GENERAL GROUPS OF INDUSTRIES DURING ONE WEEK IN JULY, 1926

	Number of establishments	Average number of wage earners
Railroads	Total Class I	1,816,818
Iron and steel, and their products	1,815	688,471
Textiles and their products	1,858	546,560
Vehicles for land transportation	971	483,843
Miscellaneous industries	408	264,375
Lumber and its remanufactures	1,048	209,582
Food and kindred products	1,460	206,535
Paper and printing	880	164,157
Leather and its finished products	368	119,790
Stone, clay, and glass products	638	112,084
Chemicals and allied products	277	87,459
Tobacco manufactures	199	43,256
Metal and metal products, other than iron and steel	206	49,578

Figures showing the proportion of technical graduates—and for our purposes, mechanical engineers—to the total number employed would be of value in this table. The Sub-Committee has not, however, found any source from which such information could be obtained. A general idea of the number of supervisory positions in which mechanical-engineering training would be of service is shown in Table 2. Care should be used, however, in the use of the total figure, due to the fact that many of the executive and staff officers fill positions requiring legal, medical, or business training. Furthermore this total does not include special apprentices or minor mechanical-department officers.

TABLE 2 NUMBER OF EMPLOYEES HOLDING POSITIONS WHERE MECHANICAL-ENGINEERING TRAINING WOULD BE OF SERVICE, JUNE, 1926, ON CLASS I RAILWAYS IN THE UNITED STATES[1]

Executives, general officers, and assistants	7,431
Division officers, assistants, and staff assistants	9,372
Architectural, chemical, and engineering assistants	7,377
Sub-professional engineering and laboratory assistants	3,968
General foremen (M. of E.)	1,466
Total	29,614

[1] Includes 16 switching and terminal companies. Data obtained from Wage Statistic Report, Interstate Commerce Commission.

A Study of the Careers of Railway Officers

The presidency of a railroad is, of course, not strictly an engineering position, but there are ambitious young mechanical engineers whose goal is that office. An analysis of the careers of the presidents of the more important Class I railroads contains much information of interest and value. Table 3 gives particulars

TABLE 3 CAREERS OF THE PRESIDENTS OF 79 CLASS I RAILROADS

	Total	Common school	High-school or equivalent	College graduate	College graduates, Per cent
Education	79	33	12	34	43
Department in Which Trained:					
Executive, financial, legal	63	29	6	28	44.4
Accounting	4	3	1	0	0
Traffic and claims	13	8	4	1	7.7
Operating and telegraph	42	22	9	11	26
Purchasing	5	2	2	1	20
Mechanical	3	2	0	1	33
Engineering, bridges and signals	25	9	2	14	56

regarding the careers of the presidents of 79 Class I railroads. Out of the 79 presidents, 34 or 43 per cent are college graduates, 12 had a high-school or equivalent education, and 33 had only a common-school education. The figures shown in the left-hand column for those trained in various departments total more than 79, due to the fact that the majority worked in several departments before becoming president. Only three railroad presidents out of the 79 have worked in the mechanical department, the college graduate being Gen. W. W. Atterbury of the Pennsylvania, and the other two being H. J. German of the Montour, and Henry Miller of the Terminal Railroad Association of St. Louis. The principal fact to be obtained from this analysis is that the mechanical engineer must compete for executive positions with men trained not only in the other engineering professions but in the legal and business as well.

Table 4 shows the results of a study made of the railroad careers of 25 railroad officers in six different grades. The right-hand column of the table shows the number of years gained by the college graduate in reaching each position listed over the time required by the non-college man in reaching the same position. The officers, selected at random, are all employed by Class I railroads.

TABLE 4 AVERAGE AGES OF 25 OFFICERS IN EACH GRADE SHOWN, TIME REQUIRED TO REACH CERTAIN POSITIONS, AND TIME GAINED BY COLLEGE GRADUATES

	Average age, years	Avg. time in R.R. service, years	College trained, per cent	Avg. time for non-college man, years	Avg. time for college graduate, years	Time gained by college graduate, years
President	58.3	30	53	34	24	10
Vice-president	50.8	28.1	48	30.7	25.2	5.5
General manager	49	30.5	16.8	31.4	26.2	5.2
Supt. motive power	43.8	25.8	44	29.9	19.9	10
Mechanical engineer	35	13.75	80	14.6	13.5	1.1
Master mechanic	47.4	22.7	20	24.1	15.2	9.4

The superintendent of motive power is the active head of the mechanical department. A master mechanic is head of the repair shops of a division, and quite often has charge of both locomotive and car repairs. On most roads, however, the master mechanic has only locomotive maintenance to supervise. The mechanical engineer usually reports to the superintendent of motive power, and his work generally pertains to the design, alteration, and selection of rolling stock and shop equipment.

How Can the College Man Gain Promotion on a Railroad?

Among the facts the young mechanical engineer would like to know before entering the employ of any company, are those relating to the manner in which promotion is gained. In other words, must he play politics; be a relative of some high officer, either through birth or marriage; or is promotion gained solely through merit? Naturally such information is practically impossible to obtain until one has been in the employ of the company for a time and has had an opportunity to discover some of the inside workings. Fortunately the majority of the Class I railroads have such large organizations that family influence and politics do not have much weight in obtaining promotion. In fact, a careful check of various records and statistics of the ownership and official personnel of the railroads shows that "family controlled" companies are few in number and are practically all small roads.

The Railway Organization

In order to understand the part that the mechanical department plays in a railway organization, a brief outline should be given. The organization of a railway company divides itself naturally into several main departments that have quite clear lines of demarcation. These departments are the legal, the traffic, the treasury, the accounting and auditing, the operating, and the maintenance.

Men of mechanical-engineering education are in demand for service in the maintenance, operating, and traffic departments. The importance of mechanical-engineering training with respect to the work performed is greatest in the maintenance-of-equipment department. The work of the traffic department can be compared to that of the sales department of a manufacturing concern, and in fact it actually does sell the services of the railroad to the shipper and traveler.

The operating department mans and moves the trains, operates the yards, and mans the stations. It is generally considered to be the most important department. Excluding those who started their railroad career in the executive department as secretary to an executive officer or as chief clerk, it is the operating department that supplies the president on most railroads. This fact was evident when collecting the data for Table 3.

The good operating man seldom finds it desirable to leave railway service to work in any other industry. When he does, it is to take a position where the executive qualities of leadership bring him greater reward.

As shown in Table 3, the engineering or maintenance-of-way department is another that has always seemed to have received proper recognition. Many railroad division engineers or chief

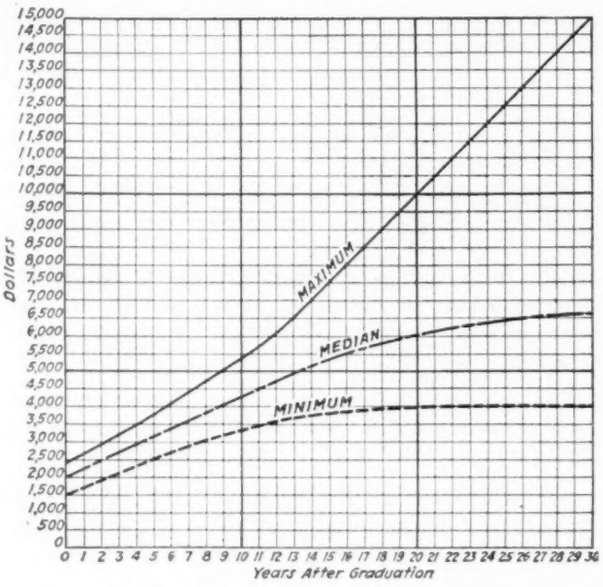


FIG. 1 CHART SHOWING THE EARNINGS OF MECHANICAL ENGINEERS EMPLOYED BY RAILROADS UP TO AND INCLUDING THE POSITION OF CHIEF OF MOTIVE POWER

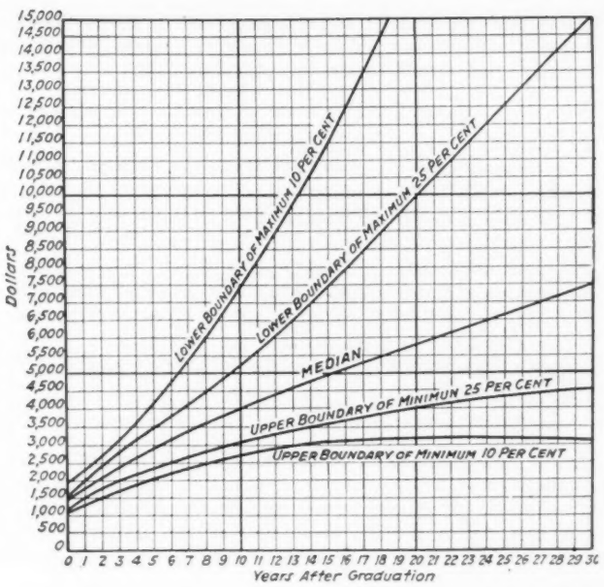

Dollars
Years After Graduation
LOWER BOUNDARY OF MAXIMUM 10 PER CENT
LOWER BOUNDARY OF MAXIMUM 25 PER CENT
MEDIAN
UPPER BOUNDARY OF MINIMUM 25 PER CENT
UPPER BOUNDARY OF MINIMUM 10 PER CENT

FIG. 2 CHART SHOWING THE EARNINGS OF ENGINEERS IN ALL INDUSTRIES BY YEARS AFTER THEIR GRADUATION FROM UNIVERSITIES AND COLLEGES

engineers have succeeded in stepping over into the operating department and thus proceeded on their way to the top. The list of railway presidents who started in railway service as rodmen or transitmen is quite a long one. This information is of interest to mechanical engineers, whose technical education is similar in many respects to that of the civil engineer.

THE MECHANICAL DEPARTMENT

The situation with respect to the mechanical department is peculiar. This department, generally speaking, is usually subordinated to the transportation department. It seems to lack a class consciousness, and in this respect is quite different from the engineering department. As stated in a preceding paragraph, this department is in charge of the design of cars and locomotives, and of their maintenance in good order. No less than 25 per cent of all railway operating expenses and from one-half to two-thirds of the expenditures for capital improvements come under the jurisdiction of this department. The January 2, 1926, issue of the *Railway Age* reports that 35 per cent of the total appropriation for capital expenditures for the first nine months of 1925 went for equipment. This shows that the job of the mechanical-department officer is one of importance and great responsibilities, and requires men capable of exercising mature judgment.

This statement is undoubtedly emphasized by the figures given in Table 5, which shows the years required for mechanical engineers to reach certain positions in the mechanical department. One mechanical engineer worked for 49 years before becoming head of the mechanical department of his road. Another worked for

TABLE 5 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN POSITIONS IN THE MECHANICAL DEPARTMENT

	Longest time	Shortest time	Average
General supt. of motive power (S.M.P.) or head of mechanical department	49	10	22.8
Assistant or division S.M.P.	36	7	18.8
Mechanical engineer	33	4	15.2
Assistant mechanical engineer	11	4	8
Engineer of tests	19	5	9.75
Engineer of motive power	24	7	18

10 years. The average time required for all those of whom the Sub-Committee obtained complete data was 22.8 years.

Table 6, which shows the number of years that have been required for mechanical engineers to reach certain railroad executive positions, cannot be considered as indicative of the actual opportunities afforded members of the profession in reaching the positions mentioned. Changing conditions in the railroad industry will, in all probability, see more mechanical engineers as railroad presidents. This is perhaps illustrated by the fact that there are now five vice-presidents who are graduates in mechanical engineering. The office of chief purchasing officer is also included in this table on account of the fact that some railroad managements consider technical training to be a necessary requirement for the duties of this position. At the present time two mechanical engineers are serving as chief purchasing officers.

TABLE 6 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN RAILROAD EXECUTIVE POSITIONS VIA THE MECHANICAL DEPARTMENT

	No. of officers	Longest time	Shortest time	Average
President	1	38	..	38
Vice-president	5	40	11	29.2
Chief purchasing officers	2	35	26	30.5

Table 7 shows the maximum, minimum, and average salaries paid for certain representative positions or their equivalents in the mechanical department in 1921. This information was obtained from a report of hearings before the Committee on Inter-

TABLE 7 MAXIMUM, MINIMUM, AND AVERAGE ANNUAL SALARIES PAID FOR CERTAIN REPRESENTATIVE POSITIONS OR THEIR EQUIVALENTS IN THE MECHANICAL DEPARTMENT IN 1921

	Maximum	Minimum	Average
General S.M.P. or head of mechanical dept.	$25,000	$4,500	$8,430
Assistant or division S.M.P.	10,200	4,000	6,660
Mechanical engineer	11,320	4,000	5,410
Assistant mechanical engineer	9,600	3,700	4,930
Engineer of tests	10,000	4,000	5,680
Engineer of motive power	8,000	4,000	5,940

state Commerce, United States Senate. Table 8 is shown for purposes of comparison of railroad salaries with those paid to engineering graduates in all industries. This information was obtained from a bulletin entitled Study of Engineering Graduates and Former Students, published by the Society for the Promotion

TABLE 8 ANALYSIS OF EARNINGS OF ENGINEERING GRADUATES AS OF JUNE 1, 1924[1]

Class	Years since graduation	Number reporting	Annual Earnings, in Dollars: Limit of lowest 25 per cent	Median	Limit of highest 25 per cent	Maximum	Most frequent
1924	0	1,191	1,200	1,476	1,560	4,080	1,200
1923	1	1,218	1,560	1,800	1,980	5,100	1,800
1922	2	1,023	1,800	2,100	2,400	9,000	1,800
1919	5	309	2,400	2,860	3,500	25,000	3,000
1914	10	498	3,110	4,000	5,100	50,000	5,000
1909	15	430	3,600	5,000	8,000	49,500	6,000
1904	20	238	4,000	5,500	10,000	90,000	4,000
1894	30	116	4,500	7,500	15,000	100,000	6,000
	Total	5,023					

[1] Study of Engineering Graduates, published by the Society for the Promotion of Engineering Education, p. 287.

of Engineering Education. In addition to the information relating to salaries given in Tables 7 and 8, curves have been plotted comparing the earnings of mechanical engineers employed in the railroad industry to the salaries paid engineers in all industries. The maximum curve shown in Fig. 1 is not as high as that shown in Fig. 2, owing to the fact that the salaries of officers above chief

of motive power were not considered. Study of these charts will show that the minimum salaries paid in the railroad industry run somewhat higher after 12 years out of college.

DIGEST OF REPLIES RECEIVED FROM RAILROADS IN RESPONSE TO QUESTIONNAIRE

A questionnaire was prepared and mailed to 85 Class I railroads on September 23, 1926, to which a total of 30 replies have thus far been received. The Sub-Committee had several objects in sending out this questionnaire, some of which are evident from the nature of the questions asked. The principal object, however, was to obtain an idea of the attitude of the railroad industry toward this project, and to learn what results might be expected from the use of the questionnaire method of collecting information. Following is a digest of the answers made to the various questions.

QUESTION (*a*). How many men of mechanical-engineering training does your company employ?

Answer. The number of college-trained men employed on most railroads is small. This may be due to the lack of demand for technical men, or it may be due to the fact that few technical men want to begin at the bottom and few are willing to face the necessary years of hard work to become proficient in the railroad business.

QUESTION (*b*). How many new men (above class) does your company employ each year?

Answer. The number of new men, technically trained, employed each year is small, except by a few of the large railroads that have adopted the policy of attracting men of technical training to their service.

QUESTION (*c*). What training does your company give mechanical-engineers entering your service? (Give outline of course.)

Answer. Only a few of the railroads give any training other than that acquired in the performance of the duties for which the men are employed. The few railroads that do emphasize practical training have apprenticeship courses embracing training in shop work on locomotives and cars, power-house work, inspection and testing of materials, and practical application of mechanical engineering.

QUESTION (*d*). What qualifications do you deem necessary?

Answer. This question has been interpreted in various ways. The general qualifications desired, however, appear to be commonsense in adapting theory to practice, close application to duties, good character, quick grasp of ordinary situations, affability, and initiative.

QUESTION (*e*). What experience do you require?

Answer. Most railroads require no previous practical experience; some, however, require two years or more of practical work after graduation.

QUESTION (*f*). What is the character of work such men do?

Answer. Work in connection with maintenance of railroad equipment, i.e., design, repairs, and inspection, also testing and valuation work.

QUESTION (*g*). What are the opportunities for advancement?

Answer. The opportunities are good, because of the few technically trained men employed by railroads at the present time, but on some roads promotion is slower than in commercial fields.

QUESTION (*h*). What are the successive positions occupied before one gets to be head of the mechanical-engineering department, or is promoted to an executive position?

Answer. There are two lines of promotion:

A—Apprentice, machinist, foreman, general foreman, master mechanic, shop superintendent, superintendent of motive power;

B—Draftsman, chief draftsman, mechanical engineer.

QUESTION (*i*). How can a man gain promotion in your company?

Answer. By display of ability to think, plan, and organize; application, energy, and loyalty.

QUESTION (*j*). What length of time is required for a man to reach a position paying, say, $5000 a year?

Answer. Some railroads do not pay this amount. On those railroads that do pay this sum, the time required would be not less than ten years, in the ordinary course of advancement.

QUESTION (*k*). What has been the experience of your company with mechanical-engineering graduates?

Answer. The railroads that have a policy of attracting mechanical-engineering graduates have had a very satisfactory experience in adapting them to the service. Most railroads appear to realize that technically trained men, on the average, give best results in the long run.

A more detailed report on these questionnaires will be given in the final report which the Sub-Committee is planning to present at the 1927 Annual Meeting.

FACTS RELATIVE TO THE RAILWAY-SUPPLY INDUSTRY

As stated in a preceding paragraph, 43 per cent of the executive and technical officers and sales staff of railway-supply concerns promoted since December, 1919, have been recruited from the railroads. A total of 517 manufacturing companies engaged in selling supplies to the railroads wholly or in part are listed in the Pocket List of Railroad Officials. Table 9 shows the number of companies engaged in manufacturing and selling certain classes of material, the railroad department responsible for selecting each class of material and its utilization, and the department from which men are usually recruited by the supply companies. These 517 supply companies employ approximately 7000 men as executives and sales engineers, a large proportion of whom the Sub-Committee have good reason to believe are men of technical education. There are also 37 private car companies that own and operate over 1000 cars that should also have need for a limited number of mechanical engineers. Six trade magazines published to serve the interests of the railroad industry employ a limited number of mechanical engineers on their editorial and business staffs. These publications, however, usually employ only mechanical engineers who have had considerable railroad experience.

TABLE 9 CLASSIFICATION OF 517 RAILWAY-SUPPLY COMPANIES ACCORDING TO PRODUCT

Material sold to railroads	No. of companies	Railway dept. concerned	Railway dept. from which men are usually recruited
Air-brake equipment and supplies	11	Mechanical Operating	Mechanical Operating
Car builders	24	Traffic Mechanical	Mechanical
Car equipment and appliances	148	Mechanical Operating	Mechanical
Electric-railway equipment	25	Mechanical Electrical	Electrical
Electric shop equipment	16	Mechanical Electrical	Electrical
Engineering construction	49	Engineering	Engineering
Forgings for railway use	5	Mechanical Engineering	Mechanical Engineering
Locomotive builders	5	Operating Mechanical Engineering	Mechanical
Locomotive appliances	26	Mechanical Operating	Mechanical
Lumber for railway use	3	Engineering Mechanical	Engineering Mechanical
Machine and small-tool manufactures	39	Mechanical	Mechanical
Shop equipment	82	Mechanical	Mechanical
Miscellaneous	28	All depts.	All depts.
Power-plant equipment	8	Electrical Mechanical	Electrical Mechanical
Rails and track supplies	89	Engineering	Engineering
Railway castings	29	Mechanical	Mechanical
Signal equipment and supplies	42	Signal Electrical Engineering	Signal Electrical Engineering
Water supply and treating	12	Engineering Mechanical	Engineering
Dealers in used railway supplies	7	Engineering Mechanical	Engineering Mechanical
Rail motor-car builders	3	Operating Mechanical	Operating Mechanical

A STUDY OF THE CAREERS OF OFFICERS OF RAILWAY-SUPPLY COMPANIES

The Sub-Committee felt it to be essential to have all the information contained in this report of as recent date as possible. Table 10, showing the careers of officers holding certain representative

positions, contains only a small number of railway-supply-company officers as compared with Table 3. In collecting data for this table only the careers of railway-supply-company officers promoted since December, 1919, were considered. An interesting item in this table is the large number of vice-presidents as compared to officers of lower rank. The reason for having 35 vice-presidents and only 12 general managers and 11 chief engineers is that the functions of the latter officers are quite often handled by men holding the title of vice-president. It is not an uncommon thing to have a "vice-president in charge of engineering" in a railway-supply company or to see the title of "vice-president and general manager."

TABLE 10 CAREERS OF OFFICERS HOLDING CERTAIN REPRESENTATIVE POSITIONS IN RAILWAY-SUPPLY COMPANIES

	No.	No. who started on R.R.	No. who started with R.S. Co.	Education			Per cent of College graduates
				Common school	High school or eq.	College graduate	
President	28	6	22	4	6	18	55
Vice-president	35	21	14	10	8	17	48.6
General manager	12	4	8	2	1	9	75
Chief engineer	11	4	7	1	1	9	81.8
Manager of sales	12	7	5	2	3	7	58.3
Railroad representative	12	9	3	2	1	9	75

Tables 10 and 11 are arranged for comparison with Tables 3 and 4. It is interesting to note the similarity in respect to time element between the careers of railroad presidents and the presidents of railway-supply companies. There is also a large degree of similarity in this respect between the vice-presidents in both industries, but a somewhat greater difference in figures appears in the careers of officers of lower rank.

TABLE 11 AVERAGE AGES, TIME REQUIRED TO REACH CERTAIN POSITIONS, AND TIME GAINED BY COLLEGE GRADUATES—RAILWAY SUPPLY COMPANIES

	Average age, years	Average time in R.R. and R.S. service, years	Average time for non-college man, years	Average time for college graduate, years	Time gained by college graduate, years
President	56.6	27.1	35.5	22	13.5
Vice-president	47.75	28.9	32.2	23.8	8.4
General manager	44.7	29.2	32.4	26	6.4
Chief engineer	46.25	33.2	41	30	11
Manager of sales	46	21.75	27.25	18.9	8.35
Railroad representative	43	27.1	3.8	20.9	17.1

Table 12 is arranged for comparison with Table 5. Higher officers are included in Table 12, however, owing to the fact that the duties and responsibilities of many railway-supply-company executives involve problems that are of a mechanical-engineering nature.

TABLE 12 YEARS REQUIRED FOR MECHANICAL ENGINEERS TO REACH CERTAIN REPRESENTATIVE POSITIONS IN A RAILWAY-SUPPLY COMPANY

	Longest time	Shortest time	Average
President	45	15	26.8
Vice-president	39	11	25.2
General manager	45	12	29
Chief engineer	36	20	26.4
Assistant engineer	22	15	19
Manager of sales	40	12	21.2
Assistant or district manager of sales	26	11	19.6
Railroad representative	43	4	21.2

It can be said that a large share of the problems confronting the president of the average railway-supply-company are similar to those of the superintendent of motive power of a Class I railroad. He should have sufficient technical knowledge to make intelligent decisions on engineering problems.

DIGEST OF REPLIES RECEIVED FROM RAILWAY-SUPPLY COMPANIES IN RESPONSE TO QUESTIONNAIRE

The same questionnaire that was mailed to the different Class I railroads was also mailed to 136 railway-supply manufacturers. Up to the time of writing this report, a total of 29 replies have been received. As in the case of the railroads, the individual answers to the different questions were extremely interesting and also showed a considerable divergence of viewpoint on the part of the various supply companies. Following is a digest of the answers made to the various questions.

QUESTION (*a*). How many men of mechanical-engineering training does your company employ?

Answer. The number varies from none up, depending entirely upon the nature and extent of the business.

QUESTION (*b*). How many *new* men (above class) does your company employ each year?

Answer. Replies to this question are vague. Few companies appear willing to commit themselves.

QUESTION (*c*). What training does your company give mechanical engineers entering your service? (Give outline of course.)

Answer. Very few supply companies have any course of training for technically trained men entering their employment. Experience in the business is the training given.

QUESTION (*d*). What qualifications do you deem necessary?

Answer. Ability to handle men, originality of thought, pleasing personality, initiative.

QUESTION (*e*). What experience do you require?

Answer. No practical experience required by some companies; others prefer at least one year of practical work.

QUESTION (*f*). What is the character of work such men do?

Answer. This depends upon the department in which the engineer is employed. It may be shop work, drafting and designing, calculating, estimating, or salesmanship.

QUESTION (*g*). What are the opportunities for advancement?

Answer. Opportunities for advancement are excellent in the large companies. Rate of advance is largely dependent upon the individual. Promotions are made only as vacancies occur by reason of changes in staff and other causes.

QUESTION (*h*). What are the successive positions occupied before one gets to be head of the mechanical-engineering department, or is promoted to an executive position?

Answer. No regular sequence of promotions except in engineering departments, in which the beginner is first a tracer, then draftsman, supervisor of design, and finally mechanical engineer.

QUESTION (*i*). How can a man gain promotion in your company?

Answer. By attention to business, loyalty, superior skill, and ability.

QUESTION (*j*). What length of time is required for a man to reach a position paying, say, $5000 a year?

Answer. No definite length of time can be determined; it will vary with conditions and individuals.

QUESTION (*k*). What has been the experience of your company with mechanical-engineering graduates?

Answer. Fairly satisfactory, but replies in general indicate some doubt on this point regarding graduates just out of college. General opinion is that technically trained men make better progress than those without that training.

INTERESTS OF RAILROADS AND THE RAILWAY-SUPPLY INDUSTRY CLOSELY INTERWOVEN

The interests of the railroads and the railway-supply industry are so intimately interwoven that it is impossible to separate them. The railroads are interested in furnishing that standard of transportation which will best meet the public requirements. They are specialists in transportation, and that in itself is no mean task. They are large purchasers of material and supplies, which is indicated by the fact that for several years—since and including 1920—the Class I railroads have expended in excess of a billion dollars a year, chargeable to the operating account for materials and supplies, exclusive of fuel for locomotives. The average capital expenditures for additions and betterments for the Class I railroads (including labor and material) for the past three years—1923, 1924, and 1925—was about $896,000,000.

The railway-supply manufacturers, specializing upon the development, production, and sale of equipment and supplies—and enjoying plenty of competition—have made a remarkable

contribution to the railroads and the public served by them. The supply manufacturer must keep in intimate contact with the railway operating problems and practices. As already brought out in this report, he frequently goes to the railroads for men for important places in his organization. He relieves the railroad organizations of production details which they are not suited to handle because of the necessity of concentrating their efforts in other directions. It is difficult to see how they can get along without each other—in fact, they are like the Siamese twins, inseparable.

From the foregoing two paragraphs, taken from Roy V. Wright's[2] paper presented at the annual meeting of the Railway Business Association, New York, November 18, 1926, we can obtain a picture of the importance of the railway-supply industry, and of the nature of the problems confronting the railway-supply-company executive. They also give an idea of the nature of the facts and information needed to be collected and assembled by the sub-committee for its final report.

Information Desired by Students

In order to make this project as complete as possible, the Sub-Committee should know what facts and information the young mechanical engineer and student in mechanical engineering desire to have regarding the railroad or railway-supply industry. It should also know the kind of facts and information needed by those who are selecting an industry to enter, whether it is asked for or not. For this reason the Sub-Committee has carefully compiled a set of questions that have been asked by students in mechanical and railroad mechanical engineering so as to furnish an outline to govern the scope of the Sub-Committee's project. Answers to many of these questions are already contained in this report, but it will readily be seen there are a number of them for which additional information must be obtained. These questions are as follows:

1 Is it desirable to enter a special apprenticeship course in order to make reasonable advancement in the motive-power department of a railroad? Why?
2 Is advancement made on the basis of merit or years of service, or both?
3 Under normal conditions of advancement, how long on the average does it take to reach the position of (*a*) assistant master mechanic, (*b*) master mechanic?
4 How do the rates of pay compare with those of other industries?
5 What is the average pay during the period of apprenticeship?
6 What roads have special apprenticeship courses?
7 Other than following out the routine schedule, do the railroads systematically train any of the younger men for higher positions? How does the training in railroad work compare with that of other industrial companies in this regard?
8 How far can one expect to advance in railroad mechanical design? Is it better to go with a builder of locomotives than with the railroads if one expects to follow design?
9 How should one apply for a Pennsylvania Railroad scholarship? Who are eligible?
10 Is it better to go with one road and stay with it, or to get general experience on a number of roads?
11 What advantages or disadvantages do the railroads have over railroad-supply companies in strictly engineering work?
12 Is there a need and call for technical men in the operating divisions of the railroads? What training is offered, and what special qualifications should one possess?
13 Does the Purchases and Stores Department offer opportunities for graduates interested in organization, sales, and management?
14 What course of study and reading may one take up to keep mentally alert while taking a special apprentice course?

To those who may have occasion to make use of the material contained in this report or in a future report on this subject, the Sub-Committee would emphasize that the information it contains is to be used only as a guide.

Respectfully submitted,
Marion B. Richardson, *Chairman*
R. S. McConnell
A. J. Wood.

[2] Managing Editor, *Railway Age*, and Editor, *Railway Mechanical Engineer*.

Heat Transmission in Water-Tube Boilers

A PAPER bearing the title of The Radiation and Convection of Heat, by Dr. T. Barratt, was read at a recent meeting of the Institute of Fuel Economy Engineers. After dealing with the theoretical aspect of the subject, and emphasizing the importance of efficient insulating materials for lagging boilers and pipes, the author turned to a brief consideration of the transmission of heat in water-tube boilers, pointing out that it might be of interest to attempt to explain why a good water-tube boiler should be more efficient than other types. In this connection the most important factors (apart from such obvious considerations as the small mass and low heat capacity of this type) appeared to be that the laws of radiation of heat (which were the same as the laws of absorption of heat) indicated that, owing to the operating of the fourth-power law, the amount of heat absorbed by a surface increased very rapidly as the temperature of the radiating body increased. For example, the heat received by a surface—say, the water tube of a boiler—at 300 deg. fahr. was more than doubled if the temperature of the furnace was increased from 2000 deg. fahr. to 2400 deg. fahr.

The laws of convection of heat, applying equally well to the heat transferred from the hot gases to the tube or boiler surface, and from the tube the water inside them, showed that for a rise of temperature of the furnace gases from 2000 deg. fahr. to 2400 deg. fahr., the increase in the heat given to the boiler tube by convection was relatively small—i.e., only about one and a quarter times, even under the most favorable conditions. There was an inert film of gas on the furnace side of the boiler tube which was untouched by convection currents, but which could be pierced by the radiation. This film might be one-fiftieth of an inch thick, though doubtless this varied with the temperature and with the speed of movement of the furnace gases. It had been estimated that 95 to 98 per cent of the convected heat was lost in forcing its way by conduction through this film of gas and, largely owing to this fact, the outside of the tube was usually only 50 to 100 deg. hotter than the inside.

Reference was made to a "dead water film" in the inside of the tube. The influence of this on the transfer of heat from the tube to the water depends on the velocity of movement of the latter. It is probable that 2 or 3 per cent of the heat received by the tube, both by radiation and by convection, is lost in forcing its way past this water film. The resistance offered to the passage of heat by the metal of the tube itself is thus only about one per cent of the total resistance, and consequently very little improvement can be effected by using a metal of higher conductivity, say, copper, instead of iron, although its conducting power is six or seven times as great. It is not very difficult, in view of these considerations, to understand the superiority from the point of view of efficiency of tube boilers over other types. A water-tube boiler can offer a relatively much larger surface to direct radiation from the furnace, while even the multi-tubular (fire-tube) boiler depends to a very large extent on convection. Another advantage with the best type of tube boiler is that the circulation of water is systematic and rapid, thus tending to remove or reduce in thickness the inert film of water inside the tube.—*Mechanical World*, vol. 80, no. 2086, December 24, 1926, p. 511.

Engineering and Industrial Standardization

INDUSTRIAL standardization consists in singling out specific products and materials, in settling upon their performance, properties, and dimensions, and in concentrating upon them both in production and in use to the end of bringing about the greatest possible industrial efficiency. It includes:

1 *Nomenclature*, such as definitions of technical terms used in specifications and contracts, also technical abbreviations and symbols.

2 *Uniformity in Dimensions* necessary to secure interchangeability of parts and supplies, and the interworking of apparatus. Dimensional standards.

3 *Quality Specifications* for materials and equipment: composition, form, and structure.

4 *Method of Tests* to determine standards of quality and performance.

5 *Ratings* of Machinery and apparatus under specific conditions.

6 *Safety Provisions* and rules for the operation of apparatus and machinery in industrial establishments. Safety codes and standards of practice.

7 *Simplification* by the elimination of unnecessary variety in types, sizes, and grades, this selection being usually based upon the relative commercial demand.

Stages of Development

The process of industrial standardization may be divided into four stages: namely, by individual firms; by societies and associations; on a national scale; and on an international scale.

Standardization by individual firms is now well developed and has been one of the main factors in establishing mass production in the United States.

Being essentially a coöperative undertaking, standardization depends for its success on organized industry, and it has naturally been taken up and carried on on an increased scale by technical societies, trade organizations, and Government departments.

National standardizing bodies have been established at present in twenty countries, all but one of which have been organized during and since the World War. They keep in active touch with each other by correspondence, exchanging information in regard to new projects, draft standards, and general tendencies in the national work in their respective countries. The national standardizing body of this country is the American Engineering Standards Committee, the work and position of which with relation to other standardizing bodies, both national and international, will be discussed later in this paper.

In some few subjects formal proposals have been made for general international standardization. There are two important international standardizing bodies, namely, the International Electrotechnical Commission and the International Commission on Illumination.

In considering standardization in the various industries, the relation of the A.E.S.C. to the various forces throughout industry working toward increased efficiency will be discussed.

STANDARDIZATION is absolutely essential in any program of mass production, and when properly applied is one of the major factors in the elimination of waste in industry. The multiplicity of standards-making bodies of a national character in the United States and the enormous amount of work they have done in the production of standards is sufficient evidence of the truth of the above statement. The American Engineering Standards Committee has grown out of the necessity for the setting up of a central body qualified to coördinate the work of the standards-making bodies and to give the stamp of approval to those standards which have, by their method of preparation, endorsement, and use, shown themselves to be worthy of being designated American Standards.

The American Engineering Standards Committee does not initiate standards but acts as a national clearing house for standardization work. An American standard may be established in two ways. The first is through a sectional committee on which all parties interested are represented, appointed under the procedure of the A.E.S.C. The other way is through the establishment and practice of a standard by a responsible body—for example, an engineering society—and then by approval by the A.E.S.C. In the latter case such approval is given only after it has been found that the principal industrial groups concerned favor the adoption of the standard.

Unfortunately the tremendous interest which has been back of the standardization movement in the United States during the last one or two decades has resulted in the formation of a large number of standards-making groups and has in itself made it difficult for those not intimately familiar with standardization work to determine where and by whom standardization along particular lines should be undertaken.

The accompanying discussion, which has been prepared by S. J. Koshkin, formerly of the staff of The American Society of Mechanical Engineers and of the American Engineering Standards Committee and now of the Mechanical Engineering Department of Sibley College, Cornell University, should go far to clear up this matter and to show the logical steps by means of which standards are initiated, developed, inaugurated, and finally brought to the status of American Standards.

C. E. SKINNER, Chairman, A.E.S.C.

The American Engineering Standards Committee

The American Engineering Standards Committee, organized in 1918, is a federation of thirty-four separate national organizations, including nine national engineering societies, eighteen national industrial associations, and seven departments of the Federal Government. It serves as a national clearing house for industrial and engineering standardization and specific matters, enabling the various standardizing forces to be so coördinated that duplication of work and the promulgation of conflicting standards are avoided. The experience of its member organizations in standardization work dates back to the very beginning of such activities in this country.

In all about 300 national organizations, trade, technical, industrial, and governmental, cooperate in the work through officially accredited representatives, and about 1600 individuals serve as such representatives on the many working committees. Of the 300 national organizations at work on standardization projects, 170 may be classed as industrial or trade associations. Over 200 projects are actually under development or have reached the status of approved standards.

In addition to the technical societies and trade associations which have contributed to the work of the A.E.S.C. as member bodies, 350 industrial companies give direct financial support as sustaining members, on a basis of annual contributions. The thirty-four member organizations of the Committee are as follows:

American Electric Railway Association
American Institute of Architects
American Institute of Electrical Engineers
American Institute of Mining and Metallurgical Engineers
American Mining Congress
American Railway Association (Engineering Division)
American Society of Civil Engineers
American Society of Mechanical Engineers
American Society for Testing Materials
Association of American Steel Manufacturers

Electrical Manufacturers' Council:
- Electrical Manufacturers' Club
- Electric Power Club
- Associated Manufacturers of Electrical Supplies

Electric Light and Power Group:
- Association of Edison Illuminating Companies
- National Electric Light Association

Fire-Protection Group:
- Associated Factory Mutual Fire Insurance Companies
- National Board of Fire Underwriters
- National Fire Protection Association
- Underwriters' Laboratories

Gas Group:
- American Gas Association
- Compressed Gas Manufacturers' Association
- International Acetylene Association

Safety Group:
- National Safety Council
- National Bureau of Casualty and Surety Underwriters

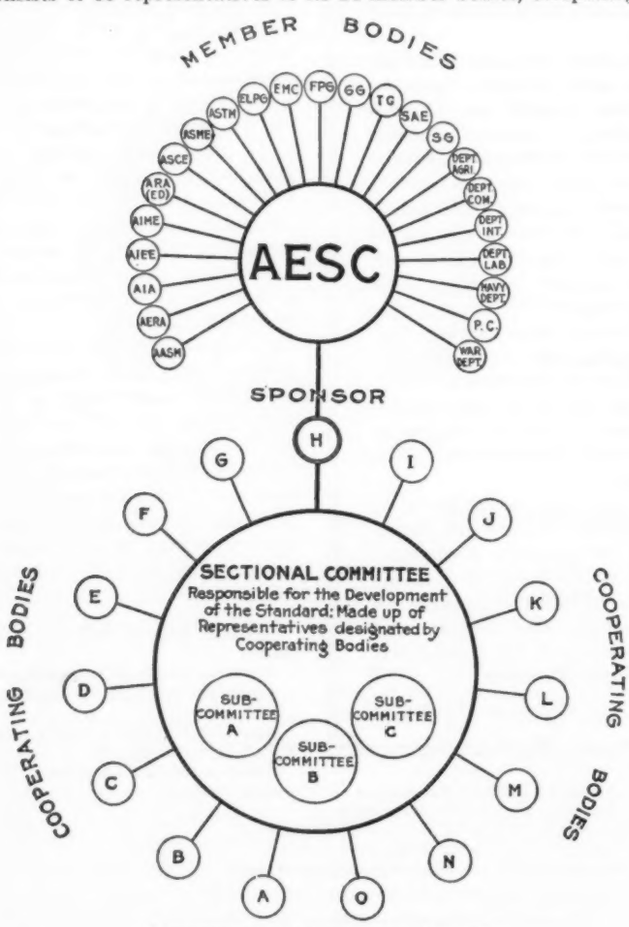
Society of Automotive Engineers

Telephone Group:
- Bell Telephone System
- U. S. Independent Telephone Association

The Panama Canal
U. S. Department of Agriculture
U. S. Department of Commerce
U. S. Department of the Interior
U. S. Department of Labor
U. S. Navy Department
U. S. War Department.

The A.E.S.C. is primarily an administrative and policy-forming body and does not itself initiate or develop standards. Through its methods and procedure all organizations concerned participate in deciding whether a given piece of work shall be undertaken, in developing the standard, and in recommending its approval. In this way the results of the work of hundreds of bodies are broadened and unified into a truly national system of standards. The growth of the Committee's work is indicative of the growth of the whole movement.

Under the constitution of the organization the whole executive authority is vested in a Main Committee, the personnel of which consists of 58 representatives of its 24 member bodies, comprising



ORGANIZATION CHART OF THE A.E.S.C.

in all 34 separate national organizations at present. Administrative sub-committees and a small executive committee act for the Main Committee in the interval between meetings. Permanent offices and staff are maintained in the Engineering Societies Building, 29 West 39th St., New York, N. Y.

Method of Work. Through a system of sponsorship, which is a distinctive feature of the A.E.S.C. procedure, making the Committee the most decentralized of all the national standardizing bodies, actual standardization work remains in control of organizations where it has always been or where it properly belongs because of closeness of interest.

Sponsorship is entirely independent of membership on the Main Committee. Two or more bodies may be designated as joint sponsors for a standard or a group of standards. The sponsor, with the approval of the A.E.S.C., organizes what is known as a "sectional committee," made up of representatives designated by all the interested bodies, and producers, consumers, and the general public are all consulted with the idea of balancing the interest. The sponsor is responsible for seeing that the work is continuously and effectively prosecuted and the necessary administrative and clerical service provided. The sponsor provides also for the publication of the standard.

The A.E.S.C. does not concern itself with the technical details of the standard and its approval simply means that it has satisfied itself; that all organizations concerned have had an opportunity to participate in the work; that the work has been carried out under a procedure that has been regular, open, and aboveboard, and that the standard represents a real national consensus on what is best in American engineering and industrial practice, and hence that it either already does or may reasonably be expected to play a significant if not controlling role in regard to the materials and processes in the industry concerned.

The relations of a sponsor to the other coöperating bodies represented on a sectional committee is somewhat similar to the relation of the chairman to the other members of a committee.

Safety Codes. An important feature of the work of the A.E.S.C., which can here be mentioned only briefly, is that in the field of safety. The industrial-safety program now includes about 50 safety codes, of which 17 have been completed, and work on a dozen others is well advanced. The Safety Code Correlating Committee is instrumental in coördinating the work in this field, thus making a planned mosaic much easier of accomplishment than is the case when each piece of work is undertaken independently. It assures the services of men thoroughly familiar with the general subject and the coöperative work of the organizations interested in it, thus giving all the advantages of a continuously functioning body steadily accumulating information and experience. The safety codes formulated according to the procedure of the A.E.S.C. have been found most useful both in the work of private companies and governmental regulatory organizations, and have been widely adopted.

Standardization Projects under A.E.S.C. Procedure. An extremely wide range of activities is represented in the technical projects submitted to the Committee. The Year Book of the Committee for 1926 lists 212 projects which include 33 in civil engineering and building trades, 56 in mechanical engineering, 30 electrical, 4 automotive, 9 transportation, 1 shipbuilding, 9 ferrous metallurgy, 14 non-ferrous metallurgy, 13 chemical, 3 textile, 19 mining, 5 wood, 1 pulp and paper, and 15 miscellaneous.

THE BUREAU OF STANDARDS

> The general function of the bureau is the development, construction, custody, and maintenance of reference and working standards used in industry and commerce. (1925 Report of the Director of the Bureau of Standards.)

The work of the Bureau of Standards is being carried on in accord with an organic act of Congress, which gives to it the custody of fundamental standards of science and industry, invests it with the function of comparing such standards with like standards used in scientific research, industry, commerce, and education; with the duplication or multiplication of such secondary standards; with the testing and calibration of measuring apparatus; with the solution of problems which arise in connection with standards, and with the determination of physical constants and properties of materials.

The results of these investigations are published in pamphlet form. They cover a wide range of subjects in the field of physical measurements and are issued for general information to the scientific, technical, and industrial interests concerned with the subject treated. The Bureau's publications are issued in seven series, designated Scientific Papers, Technologic Papers, Circulars, Handbooks, Simplified Practice Recommendations, Building Code Recommendations, and Miscellaneous Publications.

Over 500 scientific papers bound in 20 volumes of approximately 750 printed pages each have been issued. Nearly 300 technological papers form 19 volumes of about the size mentioned above. Over

200 circulars, five handbooks, and over 100 other items of various degrees of importance have been published.

The laboratories and offices of the Bureau are located on a tract of about 43 acres in the northwest section of Washington, D. C., on Pierce Mill Road near Connecticut Avenue. The organization of the scientific and technical staff is based upon the nature of the expert service involved rather than upon the classes of standards. The main divisions are as follows:

1	Electrical	7	Structural engineering and miscellaneous materials
2	Weights and measures	8	Metallurgical
3	Temperature and heat	9	Ceramic
4	Optical	10	Building and housing
5	Chemical	11	Simplified practice.
6	Engineering physics		

Of these divisions the last only will be considered here briefly.

Division of Simplified Practice. The chief function of this division is to serve as a centralizing agency in bringing together producers, distributors, and users of specific commodities, to ascertain the conditions existing, determine needed remedies, and to support the recommendations of those interested when they shall mutually agree upon simplifications of benefit to the industries and the public concerned. The division's activities are purely coöperative in character, and initiative must come from business itself. More than 545 industrial groups are at present coöperating with this division, which was established in 1921 by Secretary Hoover as one of the units in a general program of the Department of Commerce to eliminate industrial and commercial wastes.

It is interesting to note that according to a survey made by the Federated American Engineering Societies and published in 1921, ten billion dollars could be saved annually through standardization and simplification alone, as this survey brought out the fact that in six industries, taken as typical, there existed a preventable waste of from 29 to 64 per cent, making an average waste of 49 per cent for the entire American business. About one-third of this waste is attributable to lack of standards and over-diversity of variety.

General conferences attended by representatives of manufacturers, distributors, and users, held at the Department of Commerce under the auspices of the Division of Simplified Practice, have already resulted in the adoption of not less than 57 simplified-practice recommendations, covering a number of specific commodities and effecting quite drastic reductions in useless varieties amounting in a great number of cases to over 90 per cent. Nearly 40 more commodities are at present in the process of simplification by the interested industries in coöperation with the Division of Simplified Practice.

Resurveys by groups affected show that there has been consistent adherence to the Simplified Practice Recommendations on the part of producers, distributors, and consumers. Savings to nine industries through release of capital investment, reduction of inventory, lowering of production, and sales costs, and improvement in qualities have been estimated to be in excess of $300,000,000 annually.

The presentation of at least a thousand opportunities for simplification, as deduced from a survey conducted under the direction of the American Engineering Standards Committee, has shown the Division of Simplified Practice many fertile fields for its services.

Unification of Government Specifications

For the unification of Government specifications and to bring them into line with the best commercial practice, a board composed of the representatives of various purchasing agencies of the Federal Government was organized under the Bureau of Budgets in 1921. This board is known as the Federal Specifications Board and is under the chairmanship of the Director of the Bureau of Standards.

Government specifications are being submitted, at first informally, for criticism by industry and to determine their acceptability to industry, through coöperative arrangements between the board and the American Engineering Standards Committee.

The Board has now adopted over 350 specifications. A detailed classified list of all these specifications is available.

National Directory of Commodity Specifications

This work, primarily intended for the purchasing departments of federal, state, and local governments, has been prepared by the Bureau of Standards with the coöperation of the Bureau of Foreign and Domestic Commerce. The volume contains classified and alphabetical lists with brief descriptions of existing commodity specifications formulated not only by public purchasers throughout the United States, but also by the nationally recognized trade associations, technical societies, public utilities, and industrial concerns. The names and addresses of about three hundred organizations that have coöperated in this undertaking by supplying copies of their specifications for listing in the classified index are given. This list includes 182 technical societies and trade organizations, 78 state, municipal, government, and public institutions, and 38 railroad and other public utilities.

The 6650 items listed in the Directory are divided into ten main classes, as follows: (0) Animal and animal products (except wool and hair), 350; (1) Vegetable food products, other than oilseeds, expressed oils, and beverages, 525; (2) Vegetable products, except food, fiber, and wood, 400; (5) Textiles, 275; (4) Wood and paper, 625; (5) Non-metallic minerals, 725; (6) Ores, metals, and manufactures (except machinery and vehicles), 1700; (7) Machinery and vehicles, 800; (8) Chemicals and allied products, 600; (9) Commodities not elsewhere classified, 650. The approximate number of specifications for all of these commodities is 27,100.

The decimal system of classification adopted is based on the source of the material rather than the use that is made of the commodity. The explanatory matter given is restricted to what is necessary for the elucidation of the scope of the particular specification.

The actual specifications or abstracts, instead of merely their titles, are to be contained in a future work, the "Encyclopedia of Specifications," which will be issued as rapidly as conditions will permit in loose-leaf or loose-pamphlet form. Initially, efforts will be concentrated in the reproduction of such worth-while specifications as are difficult to secure.

Copies of the National Directory of Commodity Specifications may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., the price per copy being $1.25. For the convenience of those who may wish to secure copies of the specifications from one rather than several sources, the American Engineering Standards Committee has arranged to act as a central distributing agent for the specifications of the national technical societies and trade associations mentioned in the Directory.

Marine Standards

The American Marine Standards Committee is a development of coöperation between the United States Department of Commerce, the United States Shipping Board, and other marine interests to promote simplification of practice in shipbuilding, ship operation, and allied industries, by encouraging, developing and promulgating in coöperation with all concerned, standards, rules, or recommendations for design, construction, and manufacture of hulls, machinery, equipment, and fittings for ships and port facilities, and materials for their maintenance and operation, particularly in relation to the merchant marine of the United States.

On June 30, 1926, the A.M.S.C. had a total of 312 member bodies, comprising representatives of all phases of the marine industry, with interlocking representation from other bodies having less direct interests, to insure proper coördination of activities and avoid duplication of effort.

Prior to June 30, 1926, the organization had developed and approved 28 standards, viz.: 16 on hull details; 1 on engineering details; and 11 on ship-operation details. It had numerous others in course of preparation, with 40 subject and 3 technical committees coöperating.

The organization also has several projects in the hands of special committees, among which are Rules for Stability and Loading of Ships, and Rules for Bulkheads.

The organization is administered as a unit of the Division of Simplified Practice of the United States Department of Commerce, but the activities are supervised and controlled by an Executive Board elected annually by the membership. The executive officer is the Secretary, whose office is in the Commerce Building, Washington, D. C.

MINING STANDARDIZATION

All the major problems of the mechanical operation of a mine are included in the scope of the work of the Standardization Division of the American Mining Congress in Washington, D. C. This organization, which was started five years ago with an attempt to simplify electrical equipment in both coal and metal mines, has grown in magnitude and importance until it is now the center of a wide range of standardization activity of interest to the mining industry. It is taking an active part in the work of the American Engineering Standards Committee and is sponsor or joint sponsor for a number of standardization projects in the mining field. It has representation on the A.E.S.C. and on the Mining Standardization Correlating Committee, advisory to the A.E.S.C.

Standardization in the two main divisions of mining, namely, coal mining and metal mining, is handled by two branches of the Standardization Division of the Congress. Each branch carries on its work through committees covering certain definite classes of work, such as mine ventilation, mine drainage, mine timbering, underground power transmission, underground transportation, power equipment, mechanical loading, fire fighting, drilling machines, steam shovels, outside coal-handling equipment, milling and smelting equipment and practices, methods of mine sampling, mine accounting, etc.

These committees are composed of consulting mining engineers, representatives from operating mining companies, and manufacturers of mining machinery and equipment, and all recommendations made by the committees must have the approval of such joint representation.

The American Mining Congress issues annual standardizational bulletins, the material of which is later combined into the Handbook of Standard and Approved American Coal-Mining Methods, Practice, and Equipment. This handbook is of the loose-leaf form.

The Bureau of Mines of the Department of Commerce is carrying on important standardization work in the mining field through a system of approval of electrical equipment and permissible explosives found to be safe for use in explosive mine atmospheres. Naturally it is most desirable that approval of machines and equipment shall be uniform in various states, otherwise the difficulties of the manufacturers will be very great. In fifteen years 71 mine explosions were caused directly by the use of black powder or dynamite, bringing about the death of 857 men and the injury of 173 others, but no case is known where an accident has been directly caused by one of the "permissible" explosives.

The Bureau also coöperates in an important way on projects under the procedure of the American Engineering Standards Committee. Its Code on Permissible Explosives has been approved by the A.E.S.C. In addition, the Bureau of Mines is sponsor or joint sponsor for the following projects: Permissible Portable Electric Mine Lamps, Safety Rules for Installing and Using Electrical Equipment in Coal Mines, Storage-Battery Locomotives for Use in Gaseous Mines, Ventilation in Coal Mines, Ventilation in Metal Mines, and the Safety Code for Coal-Mine Illumination. The Bureau is also coöperating through representation on 15 projects, under the procedure of the American Engineering Standards Committee. The Mining Standardization Correlating Committee acts in an advisory capacity to the A.E.S.C., suggesting subjects for and determining the desirability of standardization in the mining fields. It defines also and limits the scope of the projects, adjusts conflicts, clears up ambiguities, follows up and expedites work in progress in the development of standards, and, in short, correlates the work of the group of sectional committees with which it is in contact.

STANDARDIZATION IN THE AUTOMOTIVE INDUSTRY

The amazing initiative and inventiveness and the great output of the American automobile industry would have been quite impossible except for standardization, which underlies all quantity manufacture. Standardization work in the field was begun 20 years ago by the Society of Automotive Engineers, the Standards Committee of which was organized in 1910 with 96 members comprised in 16 divisions. This Committee has grown until it now has 300 members organized into 29 divisions.

More than 600 standards have been formulated and widely adopted, applying to engines, electrical systems, parts and fittings, materials, etc. These may be broadly divided into production standards and parts replacement or service standards.

Prior to the work of the Standards Committee there were 1600 different sizes of seamless tubing used in building motor cars. These have now been reduced to 20 sizes, made in large quantities at much lower prices. Head-lamp lenses of 88 different sizes have been reduced to four. Careful estimates show that a saving of about 15 per cent of the total retail value of American automotive products has resulted from S.A.E. standardization.

The carrying on of standardization work in this industry during the past year has required the holding of 32 division and subdivision meetings, representing every aspect of the work. Standardization work is now in progress on more than 60 subjects.

The S.A.E. Handbook, distributed to the members of the society and to other experts, is an invaluable collection of standardization data universally used by the automotive engineer. Its sections are as follows: (A) Power Plant; (B) Electrical Equipment; (C) Parts and Fittings; (D) Materials; (E) Transmission; (F) Axle and Wheel; (G) Tire and Rim; (H) Frame and Spring; (J) Control; (K) Nomenclature and Tests; (L) Body; (M) General.

STANDARDIZATION IN THE ELECTRICAL INDUSTRY

Standardization activities in the electrical field are divided among several organizations, each covering a definite field and the work of all is so arranged that there is a minimum of overlapping in efforts. The bodies responsible for the preparation of the largest number of standards in this field are three in number and are as follows:

1 The American Institute of Electrical Engineers
2 The National Electrical Manufacturers Association
3 The American Electric Railway Association.

To more clearly indicate the importance of each of these organizations in electrical standardization, they will be discussed separately and the work of each over its period of activity in this very valuable work mentioned.

1 *The American Institute of Electrical Engineers.* The appointment of a committee of seven in 1898 to develop standards and specifications covering generators, motors, and transformers marked the beginning of standardization activities of the A.I.E.E. The results of this committee work, approved in 1899, became and have continued with subsequent revisions to be recognized throughout the United States as the authoritative source of information on the terms and conditions which characterize the rating and behavior of electrical apparatus, with special reference to the conditions of acceptance tests. Subsequent reports of the Standards Committee in the form of Standardization Rules were issued in 1902 and 1906. These Rules comprise the substance of 40 different groups of standards. At present the main activities of the Institute's Standards Committee are concentrated on the general revision of its standards, which involves their separation into a large number of pamphlets each dealing with a specific class of apparatus.

The revised sections of the Institute's standards are later placed under A.E.S.C. procedure and, together with similar material adopted by other organizations, form the basis for coöperation in the preparation of American Electrical Standards. The Institute is now sole sponsor for four projects under the A.E.S.C. procedure, is joint sponsor with others for seven other projects, and is represented in about 20 other sectional committees.

The present membership of the Standards Committee is 37, with 29 sub-committees, specializing on various subjects, involving the work of 200 individuals. The present activities of the Institute in standardization extend over 20 years of active work in standardization of design, manufacture, operation, and specification of electrical apparatus.

Standards of the American Institute of Electrical Engineers are now published in the form of a series of pamphlets, each pamphlet dealing with a specific subject. This is to simplify the process of keeping the standards revised to conform with the latest development and to enable those interested in a particular field to obtain by itself the material covering that field.

Through the intermediary of the U. S. Committee of the International Electrotechnical Commission, of which it is one of the leading members, the Institute participates in a very active way in the formulation of international electrical standards for nomenclature, symbols, rating, and testing.

The I.E.C. is an international body in the electrical industry. It represents 24 nations and arose out of the International Electrical Congress, which was held in St. Louis, Mo., in 1904 under the auspices of the A.I.E.E. To this committee has been due much of the international coöperation that has obtained in the electrical industries, by which greater uniformity of practice, nomenclature, and rating has opened foreign markets to American electrical industries.

For 15 years the A.I.E.E. exclusively supported the U. S. Committee of the International Electrotechnical Commission, but recently it has had the support of other organizations in the field also. It is the medium through which the Institute's standards, representing electrical practice in America, are communicated to the International body, and through which its Standards Committee learns the views of other countries.

2 *National Electrical Manufacturers Association.* The N.E.M.A. was organized for the standardization, improvement in production, and the increase in distribution of electric machinery apparatus, and supplies. It is made up of manufacturers of electric-power apparatus, control equipment, and supplies, and in its standardization work coöperates very closely with the American Institute of Electrical Engineers and the American Engineering Standards Committee.

Efforts of the work of the technical committees of the Association and of its predecessors over the past seventeen years have resulted in a series of standards covering the manufacture, test, and performance of all kinds of electrical generators and motors, electric tools and grinders, mining and industrial locomotives and storage batteries for their operation, industrial control equipment, transformers, balance coils, switchboards, oil circuit breakers, and other electric-power apparatus and control equipment produced in the United States. These standards and practices are published in handbook form and are carefully revised to keep pace with the latest developments in the field.

The offices of the association are located at 30 East 42nd St., New York. A branch office is maintained at Cleveland, in the B. F. Keith Building.

3 *The American Electric Railway Association.* Since its organization in 1906, this association has developed more than 130 standard designs, specifications, and practices. Of the rail production for electric railways in this country, 75 per cent is in accordance with the A.E.R.A. standards.

A Committee on Standards is maintained to coördinate the work of the Association's committees in the fields of buildings and structures, power generation and distribution, equipment, purchases and stores, signaling, way material, wood preservation, and car and house wiring.

The annual Engineering Manual, which incorporates the standards of the Association, is the standard reference of the electric-traction industry on engineering problems.

Electrical Advisory Committee. For the purpose of correlating standardization work in the electrical field, there has been organized a general-policy committee advisory to the American Engineering Standards Committee on electrical matters. This committee will function in much the same manner as the Safety Code Correlating Committee and the Mining Standardization Correlating Committee, which have been in existence for some time and have rendered valuable service in the formulation and promotion of safety codes and mining codes.

The functions of the Electrical Advisory Committee are to advise the A.E.S.C. and other committees on all questions of policy relating to electrical standards and to serve as a general coördinating committee in the electrical field within the scope of the constitution, by-laws, and rules of procedure of the American Engineering Standards Committee; such functions include the recommending of sponsors, defining and limiting the scope of projects in the electrical field, adjusting disputes, clearing up ambiguities, following up and expediting work in progress in the development of electrical standards, and reporting from time to time to the Main Committee upon progress made within its particular field of activities.

Railway Standardization

While in the foregoing, railway standardization has been discussed to a certain extent, only that part pertaining to electric operation has been covered. Both steam and electric roads have many common problems which might well be studied by standardization groups of both systems. The American Railway Association first entered upon the task of standardization with the adoption of a uniform code of hand, whistle, and bell-cord train signals, a matter of most vital importance to the safe movement of traffic. Basic rules or codes have been adopted on such subjects as sealing of cars, storage of cars on tracks, preservation of wrecked freight, railroad track-scale tests, weighing and reweighing of L.C.L. freight, etc. The standardization of rail sections and joints also has been given continuous study.

So great is the amount of standardization work going on in this organization that it is impossible to touch upon more than a few of the projects here. In the Telephone and Telegraph Section, for example, over 20 specifications have been adopted, requiring the work of 20 large committees and sub-committees. In the Engineering Division, known also under the name of American Railway Engineering Association, 45 specifications and standards have been adopted by the Construction and Maintenance Section and the Signal Section has been responsible for the preparation and adoption of 95 specifications. The Engineering Division has 15 large committees at work on standardization problems, including a special correlating committee, and likewise various committees under the separate sections of the divisions. This division publishes a compendious manual of standards covering nearly 1000 pages, representing an enormous amount of basic and significant technical work, and is indispensable to the successful and economic operation of our railway systems. Over 170 standards and specifications covering general design and details of cars, and materials used in their construction, have been adopted by the Mechanical Division. This division also has an extensive and complete committee organization for standardization.

Standardization in the Petroleum Industry

There has been a spontaneous movement in the petroleum industry to simplify, standardize, and improve oil-country drilling equipment and methods. Most of the problems arising have been found to be national in scope.

All standardization work in this field comes under the direct supervision of the American Petroleum Institute, which through its Division of Standardization, created as a result of the annual meeting of the Institute in St. Louis in December, 1923, maintains close touch with the problems of the industry and coöperates with and assists in correlating standardization and simplification work already under way. Several committees have been in operation on various subjects for the past two years and a number of standard specifications in pamphlet form have been already issued.

Specification No. 3, for example, deals with dimensional standards for drilling-tool joints, and specification No. 5 covers oil-country tubular goods. It has been recommended that these specifications be carefully reviewed.

The Institute is now officially coöperating with the American Engineering Standards Committee on six standardization projects. The headquarters of the Division of Standardization is in Room 1103 Santa Fe Building, Dallas, Texas.

American Society for Municipal Improvements

One of the objects of the American Society for Municipal Improvements, founded in 1894, is to promote the best methods to be employed in the construction of municipal works, and the Standard Specifications for Municipal Construction, prepared by the various specification committees of the society and adopted by it, are now widely known.

Among other standard specifications of the society are: Specifications covering sheet asphalt paving; fine aggregate asphaltic-concrete paving; street-railway track, and sewers. The various standards are published in the "Proceedings" of the annual conventions of the society.

The society is co-sponsor with the American Society for Testing Materials, the American Association of State Highway Officials, and the Bureau of Public Roads for the following five standards developed under the procedure of the American Engineering Standards Committee and recognized as American Standards: Method of Test for Penetration of Bituminous Materials; Stone, Slag, Gravel, and Stone-Block Sampling; Test for Apparent Specific Gravity of Coarse Aggregates; Cement-Grout Filler for Brick and Stone Pavements; and finally Specifications for Block for Granite Pavements. It is also officially coöperating in twenty other standardization projects of the A.E.S.C.

STANDARDIZATION OF MATERIALS

Prior to 1902, when the first movement to standardize materials was begun by the American Society for Testing Materials, there was confusion, and frequent controversies occurred between producers and consumers. The American Society of Mechanical Engineers had studied the problem and in 1890 published a report, but it was apparent that there should be some means for more effectively bringing the interested parties together and establishing standards upon which both could rely with safety. The activity following the move of the A.S.T.M. has been exceedingly beneficial, and some idea of the amount of work done in the standardization of materials may be gained by briefly reviewing the work of this society.

In the twenty-four years devoted to the work the A.S.T.M. has published over 400 standards and tentative standard specifications, amounting to 2000 book pages. There are 40 committees, having a membership of 1000, engaged in the work.

The society's cement specifications are the standard for that material throughout the country. Its drain-tile and sewer-pipe specifications are accepted as standards by the manufacturers, and their use is urged by those concerned in the interest of high quality and standardization of product. Its metal specifications appear in the legal requirements, specifications, and codes of many states, municipalities, and federal departments. Practically the whole of the society's budget of $75,000 per annum, to which should be added large contributions of time and expense by the 3500 individual and company members of the society, is devoted to standardization work of broad and diversified character.

It is now sole sponsor for 42 projects under the A.E.S.C. procedure, joint sponsor with others for 12 other projects, and is represented in 13 other sectional committees.

Standard specifications, methods of test, definitions of terms, and recommended practices are issued every three years in book form. The last Book of Standards, bearing the date 1924, contains 220 standards in effect at the time of its publication.

Those standards which are adopted by the society in the intervening years are published separately and also collected into its annual supplements to the Book of Standards.

STANDARDS FOR DESIGN, CONSTRUCTION, AND TESTS

For the purpose of bringing to the user the best obtainable opinion on the merits of appliances, devices, machines, and materials in respect to life, fire, and collision hazards, also theft and accident prevention, the Underwriters' Laboratories, Inc., was established and is maintained by the National Board of Fire Underwriters. The laboratories are conducted for service and not profit, and were chartered by the state of Illinois in November, 1901. The principal offices and testing station are located at 207 East Ohio St., Chicago, Ill.

One of the most widely circulated codes of the laboratories is its Code for Electrical Appliances. It consists of standards for design, construction, and tests of devices and materials for use in electrical circuits for light, heat, and power, and for the forms of supervision of such products marketed under inspection and listing by the Underwriters' Laboratories. The Code is in loose-leaf form and easy to keep up to date. The following standards are included in it and may be also obtained as separate pamphlets: Armored Cables and Cords; Cabinets and Cut-out Boxes; Cartridge Enclosed Fuses; Cut-out Bases; Electric Ranges; Electric Signs; Fixture Wires; Flexible Cords; Flexible Non-Metallic Tubing; Ground Clamps; Heater Cord; Knife Switches; Panelboards; Renewable Cartridge Enclosed Switches; Rigid Conduits; Rubber-Covered Wires and Cables; Snap Switches; Soldering Lugs. Additional standards are constantly under consideration and in preparation. Lists of inspected electrical appliances which have been examined and tested and found to comply with the standards of the laboratories are published semi-annually.

The 1925 edition of the National Electrical Code was submitted under the sponsorship of the National Fire Protection Association to the American Engineering Standards Committee and is now formally approved as "American Standard," a 1926 supplement to the Code has very recently been approved.

STANDARDIZATION IN THE FIELD OF MECHANICAL ENGINEERING

The growth of the art and practices of mechanical engineering has made it necessary to devote considerable attention to standardization in this field. One of the first attempts in this direction was made by The American Society of Mechanical Engineers in 1885, when its first standards committee was organized. The first task entered upon by this newly created committee was the standardization of pipe and pipe threads.

In 1892 the Society published its first report on pipe flanges, work in which it is still active through its joint sponsorship in the standardization of pipe flanges and fittings now carried on under a large working committee of 60 individuals representing over twenty organizations.

Since 1911 the Society has maintained a standing committee on standardization which correlates its work on projects in this field. The first chairman of this committee was the late Henry Hess, known everywhere as a pioneer in this field. Manufacturers coöperate effectively in supporting the mechanical standardization work of the Society, which now comprises 24 distinct projects. Twenty-seven standards have been approved to date and there are 13 in the process of formation. The various drafts and standards issued by the Society are published in its official journal and also in the form of pamphlets for distribution.

It is also interesting to note that The American Society of Mechanical Engineers is one of the five founders of the American Engineering Standards Committee and has, in the main, organized its standardization work according to the latter's procedure, with two notable exceptions, these being the A.S.M.E. Power Test Codes and the A.S.M.E. Boiler Code, both of which are touched upon in the following paragraphs.

CODES

In dealing with the various industries which have contributed to the vast program of standardization, mention has been made of the codes formulated. In no case, however, has there been an extensive elaboration on the importance of these codes in the industries discussed, but in the field of mechanical engineering, which is so very broad in its scope, there are two codes which have great bearing on safety and the determination of power-plant efficiency. A brief discussion of these is therefore in order.

A.S.M.E. Power Test Codes. The purpose of these codes is to provide standard directions for conducting and reporting performance tests of power-plant and heat apparatus. The work started in 1886, and the first code, entitled a Standard Method for Steam Boiler Trials, which has since undergone several revisions—made necessary by the progress of the art—soon became the standard practice of the profession.

The Test Codes which have been completed to date are: General Instructions; Stationary Steam Boilers; Reciprocating Steam Engines; Condensing Apparatus; Displacement Compressors and Blowers; Feedwater Heaters; Evaporating Apparatus; Internal-Combustion Engines; Hydraulic Power Plants and their Equipment. Fourteen other Codes are being revised or developed for the first time.

A.S.M.E. Boiler Code. The purpose in developing this Code was "to formulate standard specifications for the construction of steam boilers and other pressure vessels and for their care in service." The work started in 1911 and the first edition, covering power and heating boilers, was issued in 1924 and has since undergone several revisions, becoming more comprehensive.

Additional Codes devoted to "rules for the care of steam boilers and other pressure vessels in service," also rules covering the construction and testing of Unfired Pressure Vessels, have been formu-

lated and were approved in 1925. Rules for the construction of economizers are contemplated.

The A.S.M.E. Boiler Code has been adopted in 19 states and 15 cities.

STANDARDIZATION IN THE WAR DEPARTMENT

A War Department technical committee, consisting of representatives from the War Department General Staff and from all branches charged with duties in connection with the supply of the Army, considers and makes recommendations on matters relative to standardization, development of type, and preparation of specifications referred to it from time to time by the Chief of Staff. It is essentially an advisory body on standardization and related questions common to the supply of the Army.

For the purpose of effecting complete coördination between interested branches of the Army during the development of types of equipment and supplies and the standardization and preparation of specifications, each supply branch has its own branch technical committee. Sub-committees are utilized as far as possible in the work of branch technical committees on subjects referred to them before presentation to the committee.

United States Government specifications approved by the Federal Specification Board form the basis of specifications for general classes of supplies and commodities prepared by the War Department. Strictly military and confidential specifications are not considered by the Federal Specification Board but dealt with by the War Department.

The War Department coöperates with the American Engineering Standards Committee and its coöperating associations and committees, thus enabling its branches to establish and maintain a direct contact with American industry.

There exists also a Joint Army and Navy Board for coördinating and standardizing specifications.

An alphabetical index of all U. S. Army specifications is published by the Adjutant General. A liberal attitude is enjoined with respect to compliance with requests for specifications from manufacturers, users, and others.

STANDARDIZATION IN THE NAVY DEPARTMENT

Standardization work in the Navy Department is perhaps the oldest and most completely organized of any department of the Government service. Over a thousand printed specifications are in the Navy files. All purchases are made under specifications, and great care is taken to insure open competition, in the interest of bidders and the general public. The Navy uses as few special materials as possible, adopting articles to correspond with commercial standards wherever possible. It maintains a list of approved suppliers for a restricted number of materials and articles which cannot be adequately described in the specifications, or would require inspections or tests extending over an inordinately long period of time.

On large orders the Navy provides for inspection at the factory of the supplier through technically qualified field inspectors operating in stated districts. The size of the organization permits a certain degree of specialization of inspectors to particular products.

The Navy carries on in connection with its work on specifications, extensive laboratory tests on a wide variety of supplies which it purchases for use on board ship and at naval stations. One bureau of the Navy Department has evolved a method of specification by which the actual performance of supplies is being used as a basis of award of contract. For example, the award may be made to that firm supplying an item which gives the most service (measured in some determinate unit of performance) per dollar of cost. The Navy buys practically no articles under brand names, but determines what characteristics are required and calls for those in suitable technical form either on the basis of a composition or structure known to give suitable results, or in terms of a certain desired performance, to obtain which the manufacturer is at liberty to use such methods and materials as he may find expedient.

INTERNATIONAL STANDARDIZATION

The American Engineering Standards Committee acts as the official channel of coöperation in general international engineering standardization and serves as the medium through which a knowledge of recognized American engineering standards are brought to the attention of interested groups in foreign countries. In addition, the A.E.S.C. makes accessible to organizations and individuals in the United States, data concerning standardization carried on or completed in foreign countries, through its exchange of drafts and completed standards with the other national standardizing bodies established in the following nineteen countries: Australia, Austria, Belgium, Canada, Czechoslovakia, Denmark, Finland, France, Germany, Great Britain, Holland, Hungary, Italy, Japan, Norway, Poland, Russia, Sweden, and Switzerland. It has on file complete sets of all standards approved by these bodies and is also in a position to supply full and accurate information on work which is in process of development abroad.

Developments now under way make it likely that an international body for general coöperation in standardization will shortly be set up. At a conference held during April, 1926, under the auspices and at the invitation of the American Engineering Standards Committee, at which 18 countries were represented through 34 delegates, the preliminary plans for such an international body were laid. While recommendations as to the details of a plan of organization were made, it was decided before proceeding to set up a new body, that conferences should be held with the International Electrotechnical Commission to see whether it should not be possible to bring about a unified organization. Such a conference was held in London in September last, at which it was decided to postpone formal action for a year, in order to give time to work out a unified organization. Such a general international body should greatly facilitate international accord on technical questions relating to numerous mechanical and other types of standardization, for which no suitable machinery has hitherto been available. Such projects include: ball bearings, bolts and nuts, screw-thread systems, paper sizes, engineering symbols, and abbreviations, specifications for metals, radio, and keys and keyways.

CONCLUSIONS

There are many more national organizations conducting standardization work as part of their activities or which assist national standardization through their research work and publications. No attempt has been made to be exhaustive and only a few typical examples have been presented here, while among those omitted many are doing splendid work in this field. The list of member bodies of the American Engineering Standards Committee given represents only some of the names. Many more are to be found in the A.E.S.C. Year Book among the coöperating bodies, and still a greater number are listed in the National Directory of Commodity Specifications, as has already been mentioned.

Information bearing on this subject will be most easily obtained by making inquiry to the American Engineering Standards Committee.

Bibliography of Tropical Woods

THE Tropical Plant Research Foundation, Washington, D. C., announces the completion of its Bibliography of the Woods of the World (exclusive of the Temperate Region of North America), with emphasis on Tropical Woods. The present bibliography, prepared by the Foundation for the Main Research Committee of the A.S.M.E., is a revision and extension, by Major Geo. P. Ahern and Miss Helen K. Newton, of one compiled in 1923 and 1924 by Prof. Samuel J. Record of the Yale Forest School, and comprises 121 8 by 11-in. pages containing over thirteen hundred references. It is divided into the following six sections: General, Tropical America; Europe; Asia and Oceania; Africa; Index to References to Special Words and Subjects. In its compilation helpful contributions have also been made by W. N. Sparhawk and others of the U. S. Forest Service in Washington, the Forest Products Laboratory in Madison, Wis., the Pan-American Union in Washington, Dr. H. P. Brown, of the New York State Forest School and by Dr. J. P. Pfeiffer, from his important publication *De Houtsoorten van Suriname*. One hundred copies of the bibliography were originally mimeographed, and twenty-five of them have been reserved for distribution to individuals or firms genuinely interested upon application to the Foundation.

Progress in Steam Research

THE fifth annual session on Progress in Steam Table Research was held on the afternoon of Wednesday, December 8, during the 1926 Annual Meeting of the A.S.M.E., Dr. D. S. Jacobus, Past-President of the Society, presided.

George A. Orrok, Chairman of the Executive Committee, Steam Table Fund, reported on the financial status of the research; L. B. Smith and F. G. Keyes told of work accomplished at the Massachussetts Institute of Technology; E. S. Mueller reported the completion of one stage of the investigation in progress at the Bureau of Standards; and R. C. H. Heck dealt with the question of formulations. Dr. Keyes stated that all the measurements of the saturated liquid volume had been completed, and that by June there would probably be available a considerable amount of data on critical temperatures. Dr. Mueller reported that the work of the Bureau of Standards should be practically completed by the end of 1927. A. D. Risteen, H. N. Davis, R. C. H. Heck, L. S. Marks, F. O. Ellenwood, M. C. Stewart, C. H. Berry, and the chairman took part in the discussion of the various reports, which latter immediately follow.

Report of the Executive Committee of the Steam Table Fund

Geo. A. Orrok, Chairman of the Executive Committee, reported as follows:

At the meeting of the Steam Table Fund in 1925, it was reported that the total subscriptions to the fund amounted to $45,375, the actual disbursements being $42,153.03, leaving a balance on hand as of December 1, 1925, of $3221.97. In addition to the above the Bureau of Standards has disbursed with its own funds something over $20,000, and certain expenses have been covered both at Harvard and at the Massachusetts Institute of Technology, outside of the funds raised by this committee.

Since that time we have raised additional money so that the figures today stand as follows:

Actual receipts to Dec. 1, 1926, amount to.....	$50,625.00
Actual disbursements to Dec. 1, 1926, amount to..	48,514.64
Leaving a balance on hand, as of Dec. 1, 1926, of...	$ 2,110.36

Your committee hopes to be able to raise sufficient funds to carry on this work as well as to complete the work at the Bureau of Standards, where this year many difficulties have been encountered and very little actual progress has been made.

Report on Progress in Steam Research at the Massachusetts Institute of Technology

By L. B. SMITH,[1] CAMBRIDGE, MASS.

A YEAR ago at this time we described in considerable detail the experimental method and the apparatus that we were using in our work at the Massachusetts Institute of Technology. At the same time we also presented a few preliminary measurements. During the past year these measurements have been extended to the critical point. In this work we have had to overcome numerous experimental difficulties. Among these I will speak of the temperature measurement and the automatic temperature control. We have made several resistance thermometers of the strain-free type recommended by the Bureau of Standards and have calibrated these against the ice, steam, and sulphur boiling points as is customary.

The first of these thermometers which was built last year was enclosed in a steel sheath and was found unsatisfactory because at high temperatures the platinum wire became contaminated in some way and gave a high delta value.

This difficulty has been overcome by building an all-glass-enclosed thermometer and the thermometer we are now keeping as a reference standard has a delta value of 1.497. Of course, everything is referred to the centigrade temperature scale. In a period of six months of use this thermometer has shown a progressive change of ice point totaling less than 0.01 deg. cent. and the ice point is not changed by heating the thermometer for a number of hours to the temperature of boiling sulphur. No change can be detected after it has been in the sulphur bath for several hours. Last year, I think, I said something about the work of Dr. Beattie at Technology on the gas thermometer. He has been delayed for nearly a year because he has had to return some of his apparatus to Geneva. We hope, however, that before long he will get this work under way and at that time will be able to compare our platinum thermometer directly with his gas thermometer and so fix our temperatures on the absolute scale.

At the present time it seems not unlikely that our temperatures at certain points of the range over which we have been working may be in error as much as 0.1 deg. cent. We really have no means of knowing now until the gas-thermometer work has been completed. The only thing I can say in that regard is that we are using platinum wire made of platinum purified by the Bureau of Standards and calibrated against the ice, steam, and sulphur boiling points, which method is being adhered to by all the investigators, so that we all ought to be on the same temperature scale.

Last year I described an automatic temperature regulator at some length, and it will be recalled that that regulator depended upon the change of resistance of a special element which forms one arm of a Wheatstone bridge. This element was immersed in the high-temperature bath and any change in the temperature of the bath unbalanced the bridge, causing a deflection in a galvanometer connected across the bridge in the usual manner. A beam of light reflected from the galvonameter shines upon a light-sensitive cell. The current from this cell is amplified and operates a sensitive relay which controls the heating current of the high-temperature bath.

About the first thing I did last year after the December meeting was to reconstruct this apparatus. The original apparatus, which I described last year, had a sensitivity of about ± 0.02 deg. cent. The present apparatus has a sensitivity of ± 0.002 deg. cent. and the sensitivity is dependent now solely upon the efficiency of stirring in the high-temperature bath. This increase in sensitivity was accomplished by using a more sensitive galvanometer and by using a much longer beam of light, about three meters long, and also by adding a second stage of amplification.

Last year Dr. Keyes spoke about the work which was being done at Technology on the calibration of pressure gages. That work has been completed and Dr. Keyes is going to report on the details. Our own pressure gage has been cross-checked this past year by calibration against the new water-jacketed mercury column of 9 meters height and against a vapor pressure at 0.0 deg. of carbon dioxide. This is an extremely reproducible pressure and it has been measured with great precision by means of the standard gages that have been calibrated to high pressures. These two measurements are in agreement and give us a value for our pressure gage of which we are very confident.

In Fig. 1, for purposes of comparison, I have plotted deviations in degrees centigrade and in percentages from the vapor-pressure measurements of the Reichsanstalt. The temperatures are given in degrees centigrade across the bottom and the upper curve gives the deviations in degrees, the lower one in percentages. You will notice in the lower curve that up to about 340 deg., the deviations are within approximately 0.1 per cent and the maximum deviation at the critical point is only slightly more than 0.2 per cent. You can get some idea of the consistency of our data from the fact that in the lower curve the average deviation of the experimental points from the curve drawn through them is one part in four thousand or 0.025 per cent.

These points each represent a series of measurements and where there are a number of points at the same temperature it indicates different series of measurements. In some cases measurements

[1] Research Assistant, Research Laboratory of Physical Chemistry, Massachusetts Institute of Technology.

were made with different thermometers; at 300 deg., for instance, points have been measured with three different thermometers, and the deviation of these various experimental points may probably be accounted for by the discrepancy in the three thermometers.

Fig. 2 is reproduced from a paper of Henning's published in 1908. Henning was at that time getting ready to measure the vapor pressure of water and was making a comparison of the previous work.

These diagrams are really a combination of two different diagrams and show the deviation in degrees centigrade of the work of all previous observers from the values given by the formula of Thiesen. On the lower portion of the slide, at the extreme right end, the deviations amount to as much as 1 deg. cent. The temperatures there are only 270 deg. cent. The upper portion

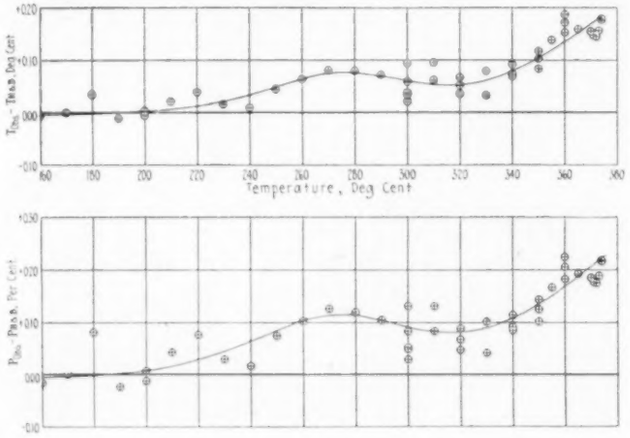


FIG. 1 DEVIATIONS FROM THE VAPOR-PRESSURE MEASUREMENTS OF THE REICHSANSTALT

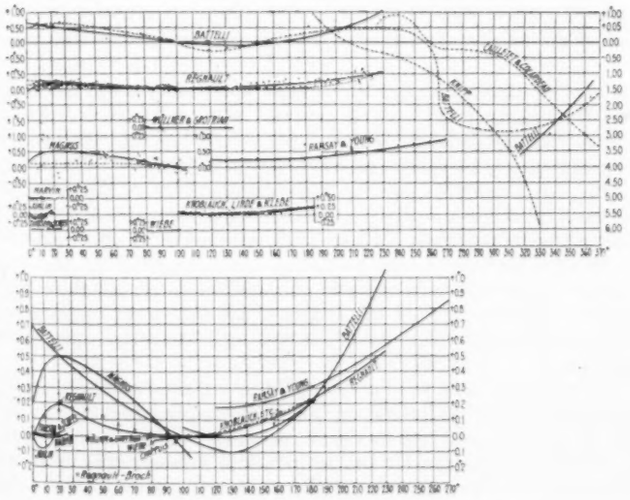


FIG. 2 SATURATION PRESSURE p OF WATER VAPOR. DEVIATIONS OF WORK OF PREVIOUS OBSERVERS FROM THE VALUES GIVEN BY THE THIESEN FORMULA

(Deviation in degrees from the Thiesen formula $(t + 273) \log (p/760) = 5.409 (t - 100) - 0.508 \times 10^{-8} [(365 - t)^4 - 265^4]$. Dotted lines, interpolations of original observers; full lines, Henning's interpolations.)

of the diagram shows the temperature running up to about the critical point and the deviations of the various observers there from the formula of Thiesen are of the order of magnitude of 3 to 6 deg. I simply give this as an indication of the unsatisfactory state of affairs before the Reichsanstalt measurements.

Fig. 3 shows our isotherms in the vicinity of the critical point. Here the pressures in atmospheres are plotted against injector testings, which are arbitrary units of volume. This doesn't exactly correspond to the steam-dome diagram because the volumes are decreasing toward the right. We conclude from these isotherms that the critical temperature is about 374.5 deg. cent. and the critical pressure about 219.5 atmospheres. The Reichsanstalt have given a value of the critical temperature of 374 and a critical pressure of about 217.8 atmospheres.

We are getting ready now to go on with the measurements in the superheat, and I imagine this is the work for which the engineers are most anxious. We have been a long time getting to it, but there has been a very large amount of preliminary work necessary.

For the small specific volumes, we are planning to use the same nickel bomb that we have used up to the present time on our vapor-pressure and liquid-density work, but for the larger specific volumes we have designed a new bomb. This is in the shape of a sphere. We have had two of these constructed of special steel. They are about $4^1/_2$ in. in outside diameter. We have chosen the spherical form because that lends itself most readily to the calculation of dilation from the elastic constants of the metal. We have had two of these bombs constructed, but they haven't been put together yet.

Fig. 4 shows the bomb and indicates how we intend to fasten the two parts together. The hemispheres fit together with a small tongue and groove and we are planning to weld them around the center where the V-shaped notch shows on the assembly.

We shall probably have all the water in the system confined within the bomb itself by means of mercury. That is the method which is used regularly in the Research Laboratory and it permits us to obtain greater accuracy on the volume measurements at large volumes than the method we have been using up to the present time where a portion of the water in the system is at a

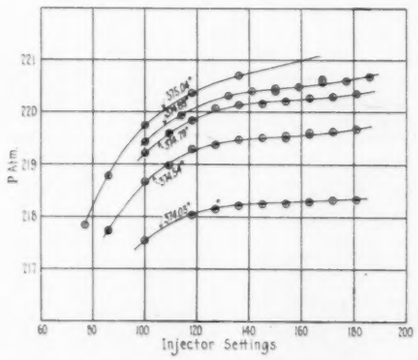


FIG. 3 ISOTHERMS IN VICINITY OF CRITICAL POINT

FIG. 4 NEW BOMB FOR USE IN DETERMINING THE LARGER SPECIFIC VOLUMES

high temperature in the form of vapor and liquid, and another portion of it is at a lower temperature in another portion of the apparatus. Where the material is distributed in that way between the high and low temperature it becomes difficult, when the total mass in the vapor phase is relatively small, to determine that mass accurately by this distribution. In the other case where all of the water is confined in the bomb, the volume measured is that occupied by the vapor alone. We shall have to make a comparatively large number of loadings of varying amounts as we will vary the specific volume by new loadings rather than by shifting water from the cool portion of the apparatus to the high-temperature portion. That will be somewhat of an inconvenience but we hope by using two bombs, one of which can be baked out and loaded while the other is in use, to speed up the work.

Report on Progress in Steam Research at the Bureau of Standards

BY E. S. MUELLER,[2] WASHINGTON, D. C.

THE occasion of the annual meeting of The American Society of Mechanical Engineers coincides approximately with the completion of one stage of the steam investigation under way at the Bureau of Standards. The design, construction, and assembly of the apparatus to be used in our measurements have been nearly completed, and it is therefore appropriate to make a brief survey of how far we have come, and to indicate, in so far as such a forecast is now possible, the future course of the investigation.

It developed very early in our consideration of plans for the investigation that the measurement of the specific heat of water, which was the first objective, was but one of a group of closely related measurements, which, when completed, would yield sufficient data to determine most of the properties of saturated water and steam. In view of this it appeared advisable, with the approval of your committee, to capitalize the experience gained in our measurements of the properties of ammonia, and to undertake the more comprehensive program of measuring the properties of saturated water and steam over the temperature range from 32 deg. to about 600 deg. fahr.

To make precise calorimetric measurements it was necessary,

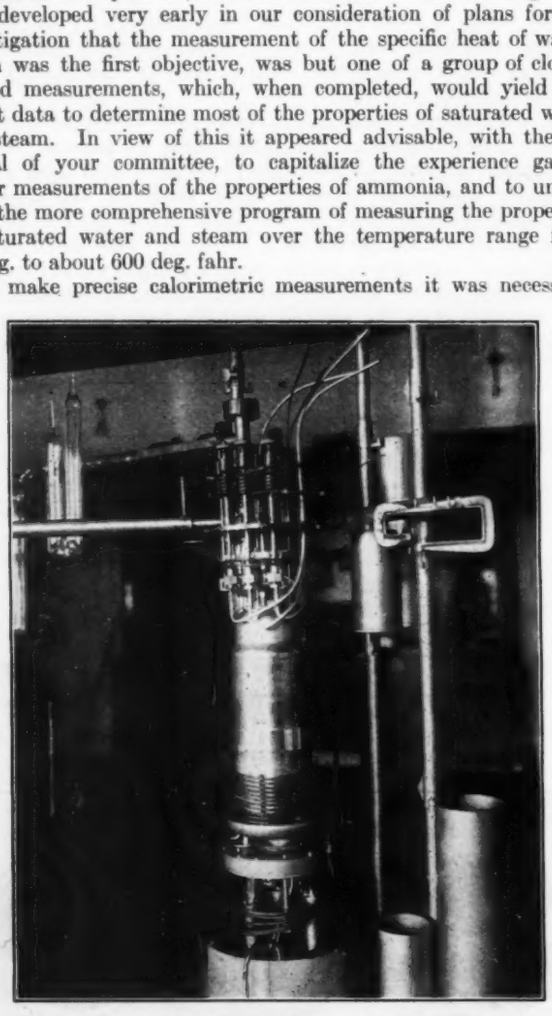


FIG. 5 STEAM CALORIMETER IN PROCESS OF ASSEMBLY

(In the center of the photograph is the envelope forming the vacuum space around the calorimeter. Above this are the various accessories for control and operation, namely, valves, heaters, cooling coils, vacuum, oil, and pressure connections, etc. Below the envelope are the accessories for controlling the oil bath.)

particularly for the higher temperatures, to provide adequate means for eliminating unmeasured loss of heat. Vacuum insulation, polished metallic surfaces, and an efficient distribution and control of heat in the calorimeter and its envelope were means adopted to conserve heat. Accuracy in measurement also required the use of pure water, which during the experiments, must be kept uncontaminated, either by air or by materials dissolved from the containers. At high temperatures water becomes more active chemically, and therefore metals which would be unaffected by water were used exclusively in the construction of the calorimeter. To obtain the necessary mechanical properties, special alloys had to be developed and used.

In the course of the experiments it will be necessary to transfer fluid from the calorimeter. In order that the flow may be completely under control, special valves and orifice meters have been provided. Since either pressure or temperature may be used as the independent variable, it seemed expedient to provide means for measuring both with high accuracy. For the temperature measurements, the temperature of the calorimeter is referred, by means of differential thermocouples, to a place where accurate measurements can be made with resistance thermometers. The steam pressure within the calorimeter can be transmitted through a thin diaphragm to any appropriate pressure-measuring device. Special deadweight piston pressure gages, accurate to one part in 10,000, have been made available for this work.

To provide vacuum insulation and to free the calorimeter and

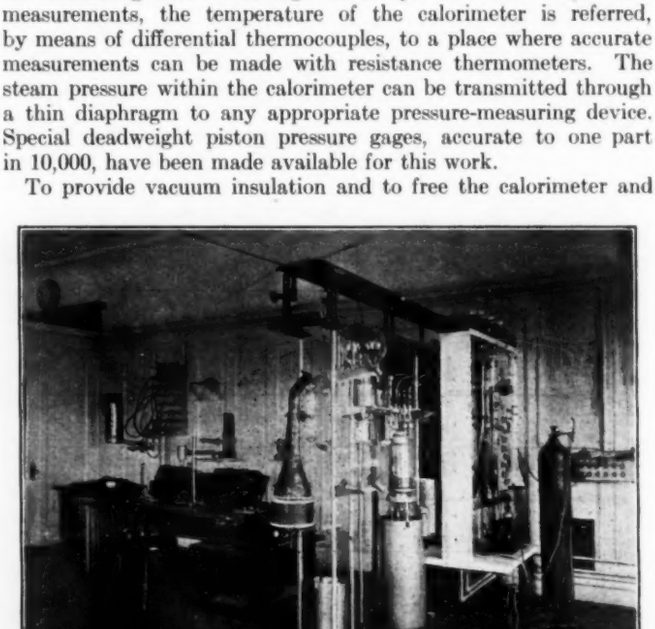


FIG. 6 STEAM CALORIMETER WITH VIEW OF LABORATORY AND SUPPLEMENTARY APPARATUS

(At left, potentiometers and Wheatstone bridge for measurements of power input, temperature differences and temperature; center, calorimeter assembled in envelope, oil bath not yet in place, and mercury-vapor pump for evacuating space between calorimeter and envelope. At right, vacuum pumps and lines for evacuating calorimeter, purifying water, and testing its purity.)

connecting lines from air, high-vacuum pumps have been provided. For the measurement of heat supplied as electric power, and for the thermoelectric measurements, potentiometers and their accessory apparatus have been assembled, and a precision Wheatstone bridge has been provided for the measurements of temperature. Views of the accessory apparatus and of the calorimeter in its envelope, as they appeared on November 29, are shown in Figs. 5 and 6.

Most of the above equipment has been described in detail at previous meetings, and there is no occasion to repeat these past reports at this time. It will suffice to indicate some of the more important items which have engaged our attention during the past year.

New heating coils were constructed to replace earlier specimens which had failed under the rigorous tests applied previous to and during installation. Methods of installing the differential thermocouples which transfer the temperature measurement from the calorimeter to the resistance thermometers, were worked out. Provision was made to eliminate effects of lead conduction in these couples, as without special precautions this might have introduced serious errors where a gradient of several hundred degrees occurs over a short length of wire. Two pressure cells with diaphragms, to be used in transmitting the steam pressure from the calorimeter to the measuring instruments outside without actual transfer of the water, were designed and built. The three resistance thermometers to be used were thoroughly recalibrated. The calorimeter was assembled and subjected to a temperature and pressure proof test by heating water in it to nearly 600 deg. fahr. the corresponding pressure being over 1400 lb. per sq. in. The mechanical and hydraulic features of the stirring system were also tested and found satisfactory. Vacuum pumps and lines have been installed.

All electrical parts as they were installed have been tested for insulation with 500 volts to insure against subsequent failure due to breakdown of insulation. Mechanical parts have been subjected to severe pressure tests.

[2] U. S. Bureau of Standards.

As far as can now be foreseen, the work of assembling should be practically completed by the end of the present year. It is not impossible that all of the observations on water and steam at saturation may be completed within the next year, although to promise this definitely would be extremely optimistic. We believe, however, that the most critical period of the work is past, not only from the experimental standpoint, but as concerns the finding of means of support. It has been apparent from the start that a protracted period of preparation would tend to cause discouragement, but it is inconceivable, with observations actually under way, that the project should be allowed to lapse for lack of support.

Mr. Osborne and Dr. Stimson have given all their time during the past year to the work and Dr. Fiock has been associated with them during the past six months. They will continue to give all their attention to the project until completion. There have been many interesting developments which under the circumstances might have been considered worthy of separate publication, but have been considered here as merely incidental, and will doubtless be described when the full account of the work is published.

Work on Pressure Standard at Massachusetts Institute of Technology

By FREDERICK G. KEYES,[3] CAMBRIDGE, MASS.

WE ARE measuring two quantities which are difficult to measure, and particularly difficult to control. Measuring pressures is a comparatively simple matter as long as you are not measuring very high ones, and in this instance we are measuring high pressures, critical pressures above 200 atmospheres, so it seemed to me that when we started the steam investigation it would be a good time also to start a separate investigation of the pressure standard. The standard of pressure is that of a column of mercury, 760 mm. in height, measured under certain very carefully specified conditions. It is necessary, therefore, to interpret the readings of one of the absolute gages that we use in the work in the terms of a mercury column.

It has been the habit of the Research Laboratory during the past fifteen years to compare our gages with a comparatively short column. The first one used was 42 ft. long, but in the new building it is possible to have one 31 ft. long. This column is compared directly, and the manner of comparison is a matter of great importance. We have finally constructed a water-jacketed column where we are controlling the temperature very carefully. In order to compare the pressures that we encounter in the steam work with our short column, we took our water-jacketed column and taking two gages of practically identical constancy, we kept interchanging the gages, applying one at the top of the column and working out a device which was the equivalent, until we had quite as high a pressure as we desired.

That work was pushed up to about 600 atmospheres, and the net result is that the effective area of our gages is constant up to about 600 atmospheres, well within the limit of accuracy of anything we will be able to do in the steam work. In all, we have about the laboratory some dozen gages, and they have all been put through the mill in this investigation in the endeavor to make sure of the pressure unit that we are quoting in these measurements which have been presented to you today. This work has all been completed and will probably be published very shortly, and of course the particular type of gages one uses makes a difference. We have been working toward a certain type that is different apparently from any one else's, but nevertheless it seems to be reliable in its indication, and we more or less standardized on it.

I feel that the pressure standard and our pressures are very reliable. I am not so confident, however, about the temperature measurements. I think when all the fog blows away about the thermometric problem, we shall find that most of the discrepancies and differences are traceable to that matter. Of course, at the present time, our standard of temperature is the platinum-resistance thermometer.

[3] Research Laboratory of Physical Chemistry, Massachusetts Institute of Technology.

There is to be a conference in Rome next June, and I hope to present some of the work that we have been doing in connection with steam tables at that conference. We shall have ready to present, I hope, the vapor-pressure data spoken of by Dr. Smith. Dr. Smith has all the measurements of the saturated liquid volume finished. They need only to be computed. Probably by June there will be some extended data available on critical temperatures, and in any event, I hope to have this all in presentable form for the Rome meeting and to let our foreign colleagues know something about what we are doing in America.

Comparison with Formulations

By R. C. H. HECK,[4] NEW BRUNSWICK, N. J.

THERE is really nothing to report from the viewpoint of formulation, which is waiting for the experimental data. Such thought as I have given the matter makes me feel doubtful whether a reasonable simple and yet correct set of general equations can be established. Those of the Van der Waals type, with specific volume as one of the primary variables, are too inconvenient in use.

In regard to the matter of the delay of steam in coming to a homogeneous static state, some interesting information was given in the report of the first Munich experiments (Knoblauch and Jakob), 1907. There steam from a boiler of fair size was mechanically dried by a specially designed separator, then passed through a presuperheater in order to bring it to the initial state for an actual addition of measured energy. This first superheater was a cylinder 18 in. in diameter and about 7 ft. high, composed of short cast-iron sections. In each section there was an individual heating coil, of flat resistance wire carried on a "pine tree" of glass tubes on a metal framework, and the temperature could be measured in each of 13 sections.

Steam flowed downward, and in many cases current was turned into the heating coils of only a few sections at the top. It was observed that after the slow current left the last active coil there was a slight drop of temperature, progressing at a decreasing rate until a steady condition was attained. As I recall, this merely guiding measurement of temperature was made with mercury thermometers.

The Effect of Phosphorus in Steel

THE writer views with the utmost misgivings any proposal to increase the amount of phosphorus in steel, and cannot regard it in any other light than as a prejudicial impurity, to be kept down to as low a proportion as possible. He asks what is free-cutting steel, and how does it differ from steel difficult to machine? The latter is tough or ductile, and does not shear away or part off readily under the severe stresses generated by the cutting edge of the tool, but, instead, drags or flows under them, tending to come away in lumps, and thus giving a very poor finish to the work.

It is often most difficult to cut good threads in such material and in extreme cases it has been necessary to water-quench nuts after they have been parted off—and thus import to them some degree of brittleness—before they can be successfully threaded. Again, "tough" steel slows down the rate of machining, causes broken collets and blunted dies, and is generally the bane of the automatic machinist.

It is regrettable that steel of this quality is often considered by engineers as "good enough for the job." In some cases it may be, but the use of free-cutting steel containing sulphur from 0.11 to 0.14 per cent, phosphorus from 0.08 to 0.10 per cent, and with an Izod value of from 5 to 10 ft-lb., led, in the knowledge of the writer, to a disastrous crop of failures. Free-cutting steel is "free-breaking" steel, and one cannot too strongly deprecate the recommendation to use more phosphorus in steel, because it is often deliberately added to steel for this specific purpose. One does not change the nature of phosphorus, always deleterious from the structural standpoint, by deliberately adding it to steel.—*Mining and Metallurgy*, vol. 7, no. 240, p. 518.

[4] Professor of Mechanical Engineering, Rutgers College. Mem. A.S.M.E.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

Recent Experiments on the Properties of Steam at High Pressures

THE following is a partial abstract of the concluding lecture of a series delivered by Prof. H. L. Callendar at the Royal Society of Arts, London. This lecture, which was delivered on Nov. 29, 1926, dealt particularly with the experimental results obtained by Professor Callendar himself, compared in parts with those of others. Among other things, the lecturer described the equipment used in these tests. The two experimental boilers were of the water-tube type and were heated electrically. The first boiler was constructed for a pressure of 1000 lb. per sq. in., and the second was of a larger size but designed for the same pressure; the latter was tested and found to be absolutely tight under a hydraulic pressure of 4000 lb. per sq. in.

The first boiler was designed for a pressure of 1000 lb. per sq. in., and for a temperature of 800 deg. fahr. It consisted essentially of 19 thin-walled tubes of nickel silver having a total heating surface of about 19 sq. ft. The tubes were spaced apart and insulated by threading them through holes in disks of uralite and were coupled up so as to form one continuous pipe. The heating was effected by passing current through the wall of this pipe from end to end, no other heat resistances being employed, and the whole was finally enclosed in an outer tube of steel fitted with end plates. This design of boiler was very easy to repair, but although worked for more than a year, the need therefor never arose. At the end of this period however, a "test to destruction" was made, and failure occurred under a pressure of 1000 lb. per sq. in. and at a temperature of 950 deg. cent., the designed working temperature being, as already stated, 800 deg. fahr. The damage done was confined to a single tube, which opened for an inch or two near one end. The injury, had it been necessary, could have been repaired in half an hour.

A ventilation valve was fitted at the center of one of the end plates, the object of which was to get rid of the moisture, which might be absorbed by the uralite disks to the extent of 20 per cent of their weight. In the absence of the ventilation provided for, the insulation might have been damaged by the wet. The ventilation valve was normally kept open, but it would close automatically should a tube burst, thus raising the pressure in the tube space.

In both cases certain anomalous results were met with when the pressure was high and the superheat low. Thus, in the case of the experiments described in the concluding lecture, in which the external heat loss was determined by splitting the supply of steam into unequal proportions between two similar calorimeters, the temperature observed was in some cases lower on the side on which the steam flow was largest, with the result that the external heat loss, as calculated, appeared to be negative, an obviously impossible phenomenon. Similarly, when the total heats were measured directly by the condenser method, anomalous results were again observed.

Take, for example, a case in which the steam was supplied at a pressure of 1100 lb. per sq. in. and at a temperature of 580 deg. fahr. When the flow was 4.773 grams per sec., the total heat found was 1212.3 B.t.u. When the flow was reduced to 1.828 grams per sec., the total heat, as measured, was 1215.0 B.t.u. The anomaly appeared to be due to a certain time lag in the evaporation of moisture entrained in the steam entering the condenser. It was never met with when the pressure was low or when the superheat was high.

In the example above taken, the large flow took about 5 to 6 sec. to pass through the superheater, and the smaller flow about three times as long. It was probable that the effect in question was always present when the steam supply was but slightly superheated, but the error involved only became serious at high temperatures. The phenomena would escape detection with the apparatus used in most of the experiments on steam made elsewhere, but had been disclosed with the simple type of apparatus used at South Kensington.

Proceeding to another matter, the lecturer said that it had long been recognized that the simple type of expression used by Joule and Thomson to represent the cooling effect could not hold good at high pressures and small superheats or near the critical point. The object of the experiments he had described in this course of lectures was to determine the difference between the actual properties of steam at high pressures and those deduced from the Joule-Thomson expression, which had proved so remarkably accurate at

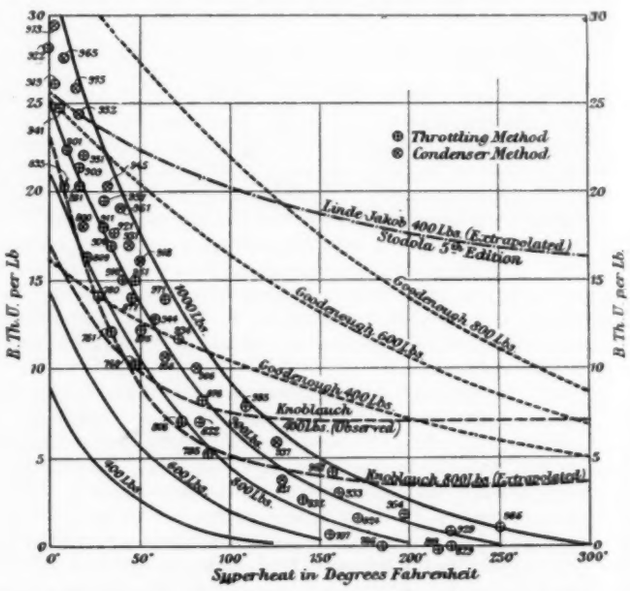


FIG. 1 DIFFERENCE ΔH FROM "ENLARGED STEAM TABLES" DURING RAPID HEATING FROM SATURATION

(The number against each observation indicates absolute pressure in lb. per sq. in.)

low pressures, the error being not more than 1 in 1000. With high superheats an equally good agreement was found to hold even with pressures as high as 1000 lb. per sq. in. When, however, a high pressure was combined with a low superheat, discrepancies came in. These were in part due, as already indicated, to moisture entrained in the steam, but also in part to the fact that the first approximation constituted by the Joule-Thomson equation was no longer sufficient with high-pressure steam near its saturation point. The actual deviations were, however, much less than was indicated by the older tables.

Comparative results were shown in Fig. 1. Here the upper curve showed a deviation from the Joule-Thomson law of the formula proposed by Linde-Jacob, and which was at one time adopted by Stodola, but had now been abandoned by him. This curve was an extrapolation based on experiments made at low pressures. The same data had been analyzed by Goodenough, with greater regard for thermodynamic principles, and this curve had also been plotted on the diagram. The deviation from the Joule-Thomson equation was, it could be seen, much less with the Goodenough curve. Knoblauch's curve for 400 lb. pressure was based directly on experiment, and this curve was similarly in shape, though not in absolute values, to that found by Professor Knoblauch. Probably the steam had been heated at about the

same rate in both sets of experiments. Knoblauch's extrapolated curve for 800 lb. per sq. in. cut the Callendar experimental curve at two points, and was in closer agreement with the Joule-Thomson equation. Goodenough's curve for the same pressure differed more, but, considering the wide extent of his extrapolation, it was a wonder that the deviation was not greater.

Knoblauch and Hansen had proposed a very ingenious but very complicated formula for the extrapolation of observations to the critical temperature.

The coefficients used were based on observations near the saturation line, which were the least reliable of any, and a second and different expression had to be used to represent the properties of steam below 100 deg. cent. Their equation for total heats above 100 deg. cent. was

$$H = 436.13 + 0.3391\,T + 0.0000985\,T^2 - 29.473\log(T - 256.4) + 46.812\log(T - F) - 0.2696\,p + 0.000301\,p^2 + 23.625\log(15.3 + p)$$

In this expression F was a function of the pressure p, viz.,

$$F = 588.97 + 0.37354\,p - \frac{6310.3}{18.165 + p}$$

This equation satisfied the condition that the specific heat of steam became infinite at the critical point, but beyond this point the value jumped to $-\infty$, an obviously impossible result. It also made the total heat of steam, at the critical point, equal to $-\infty$, whereas the actual value was positive and fairly large. It had nevertheless

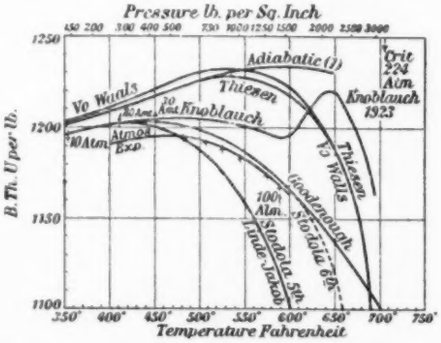


FIG. 2 FORMULAS FOR TOTAL HEAT AT SATURATION

been suggested that a formula of this type might be safely taken as a basis for estimating the value of experiments made at high pressures and temperatures.

In spite of its defects, the formula gave very fair results up to 800 lb. per sq. in., but beyond this limit it was certainly unsatisfactory. The values it gave for the total heat at saturation were too low, and, as indicated in Fig. 2, became wobbly at pressures beyond 1200 per sq. in.

It would be seen that the results for saturated steam derived

COMPARISON OF STEAM TABLES AT HIGH PRESSURES

	Marks and Davis	Stodola	Callendar	Knoblauch	Goodenough	New chart
Upper limit of table (lb. per sq. in.)	600	1422	2000	850	800	1200
Means of extrapolation	graphic	....	....	graphic	formula	....
1000 lb. per sq. in. abs. 750 deg. fahr.: Specific volume (cu. ft. per lb.)	....	0.654	0.677	0.625	0.659	0.648
Adiabatic heat drop to 200 lb. per sq. in., B.t.u.	163.8	163.8	166.6	164.7	162.8	162.9
500 lb. per sq. in. abs., 725 deg. fahr. Specific volume (cu. ft. per lb.)	1.402	1.346	1.362	1.318	1.356	1.340
Adiabatic heat drop to 150 lb. per sq. in., B.t.u.	126.4	131.7	132.1	130.5	131.8	131.1

from the Joule-Thomson adiabatic agreed with the Thiesen curve up to a temperature of about 500 deg. cent.

In practice high-pressure steam was not likely to be used with a low superheat, as the result would be a large condensation in the turbine with consequent additional friction, leakage, and wear. Moreover, the saturation line had little significance in turbine practice since, owing to the rapid expansion, condensation did not commence till the temperature had fallen some 50 deg. fahr. or more below that corresponding to the pressure. With a pressure of 1000 lb. per sq. in. the superheat should be at least 200 deg. fahr., and then the Joule-Thomson expression became pretty accurate. Indeed, it was very accurate at all pressures if the superheat were high. It seemed, therefore, to provide a far better standard of reference than such very complicated empirical formulas as that of Knoblauch and Hansen. This, moreover, could not be used to calculate heat drops, while the Joule-Thomson expression had the simple formula

$$H_0 - H = (H_0 - B)\left[1 - \left(\frac{P}{P_0}\right)^{\frac{3}{13}}\right]$$

(*Engineering*, vol. 122, no. 3178, Dec. 10, 1926, pp. 712–714)

Short Abstracts of the Month

AERONAUTICS

New German Passenger Aircraft

A NUMBER of new types have been developed. Among these is the Albatros passenger airplane L-73, which is a twin-engined biplane designed to accommodate ten passengers. The entire frame is of metal, steel tubing and drawn duralumin rods, while the covering of the wings and the body is of cloth and plywood. The airplane is driven by two 240-hp. engines equipped with pneumatic starters. If one engine should fail the other engine would be capable of maintaining the machine in flight. The steering gear, particularly the altitude rudder, is of somewhat peculiar construction. The Dornier "Merkur" airplane is fitted with a 450-hp. motor made by the Bavarian Motor Works. It is an all-metal machine built both as a passenger and freight carrier. One of these machines, in June, 1926, set up seven new international records with useful loads of 500 and 1000 kg. The same company recently completed a new giant hydroplane called "Superwal." It has seating accommodations for thirteen passengers and the fuel tanks are designed to hold sufficient fuel for a flight of about 2000 km. (1243 miles).

The Rohrbach Company lately completed two new types of machines. The first, a hydroplane, is built in monoplane form and is equipped with two 240-hp. B.M.W. (Bavarian Machine Works) IV engines. In the second Rohrbach machine, designed for land flights, there are three engines of the same type, the two lateral engines being suspended underneath the planes and supported in two steel brackets each.

The Udet "Kondor" airplane is a high-decker with four 100-hp. engines, each engine driving a pressure propeller through an intermediate shaft almost 6½ ft. on length. The object of this novel arrangement was to create a passenger airplane that would be absolutely reliable and the machine was designed so that it would be able to continue the charging if one or even two of the engines should happen to fail. The engines are located underneath the wings and the propellers are at the ends of the engine gondolas so as to blow straight out to the rear. The engines are of the air-cooled nine-cylinder Siemens type. The crankshaft has an extension 6 ft. 3 in. in length and connects with the propeller with a three-link universal joint.

The Junkers G-31 is a big machine equipped with three Junkers engines with a combined output of about 1000 hp. It is claimed that the airplane loaded up to its full capacity and weighing close to seven tons can attain a speed of 300 m.p.h. (Capt. Oefele, Munich, in *Engineering Progress*, vol. 7, no. 12, Dec., 1926, pp. 313–317, 13 figs., *d*)

FUELS AND FIRING

Oil Fuel for Steam Boilers

IN BURNING fuel oil in boiler furnaces a full supply of air to the burners must be maintained, otherwise partially burnt fuel passes into

the flues, where it may reignite and cause serious damage. In one case which recently came under our notice the "secondary" flame did damage in a boiler side flue, and in another instance it occurred in an economizer flue.

Owing to the long flames, and also to the possibility of this reignition of the waste gases after partial burning, the shell plates may be exposed to high gas temperature, and therefore when burning oil the scaling of shell plates is just as important as that of furnace plates.

In using oil in horizontal cylindrical furnaces with the grates removed, the lower parts become effective heating surface. These parts are commonly neglected as regards scale, but require the same attention as other parts and should be kept quite clean at the water side when exposed to heat.

The oil flames should not strike the furnace plates directly, as, apart from any risk of overheating, the flame is thereby cooled and combustion checked, resulting in black smoke and waste of fuel.

Seams should be proteced from the direct impact of flame.

It is not necessary to line the furnaces with brickwork if the plates are clean at the water side, but a screen or bridge of brickwork for the flames to play upon is a great aid to combustion. If the furnaces are lined, the flames do not give up their heat in these parts, and the furnace tubes or combustion chamber beyond the brickwork lining have to take up excess heat. In vertical boilers the flame should be inclined downward on to brickwork, care being taken to protect the base seam. Water-tube boilers with large combustion spaces lend themselves well to oil firing, but here also care should be taken to keep the flame from striking directly on the water tubes, drums, and headers.

Flue-gas explosions are more apt to occur when oil fuel is used than with coal or coke, and precautions are necessary in order to avoid them.

Unburnt or partially burnt oil in the flues is liable to explode.

Volumes of unburnt gas may pass into the flues if, for instance, a burner fails temporarily and is not at once shut off or relighted. Again, undue restriction of air supply to the burners will result in filling the flues with partially burnt gas.

Both these conditions are dangerous, and we recommend that the following precautions be observed in order to avoid gas explosion.

The flames at the burners should be under constant observation. Should a flame be accidentally extinguished it should at once be relighted, or the oil shut off. If the burner has been discharging unburnt oil for an appreciable time the oil must at once be shut off and time allowed for the flues to clear before relighting.

The dampers should never be closed when burning oil. Steam output should be regulated only by the oil, steam, and air supply at the burners.

Under proper conditions there should be a light gray smoke from the chimney; dense black smoke indicates incomplete combustion, and white smoke shows that excessive air is being used.

Using oil and coal or coke together is not altogether desirable, although very convenient when the available coal supply is inadequate. In ordinary furnaces, such as in the Lancashire boiler, the combustion space above the grate is too small for the satisfactory combustion of oil fuel, and it is more satisfactory to burn coal only in one furnace and oil only in the other.

Oil leakages are, of course, very objectionable, and may be dangerous, especially if the oil finds its way into boiler flues. It will vaporize there and very likely explode.

Fuel oil in the open is not particularly dangerous, as it has to be finely divided before it will burn readily. But vapor from heated oil is another matter, and members will be well advised to adhere to their fire-insurance companies' instructions as to necessary precautions. (Text of a memorandum circulated by the Manchester Steam Users' Association to its members and reprinted in *The Engineer*, vol. 142, no. 3700, Dec. 10, 1926, p. 632, *d*)

The Fusion Process of Low-Temperature Carbonization

THERE has just been issued by H. M. Stationery Office a report on a test made by the Fuel Research Board on the "Fusion" rotary retort installed at the works of Electro-Bleach and By-Products, Ltd., at Cledford, Cheshire, by the Fusion Corporation, Ltd., of Middlewich, Cheshire. Below are given some extracts from this report.

The plant in question has a nominal capacity of five tons of coal a day, but during the trials, which lasted for four days, only $3^1/_2$ tons of cannel coal were put through every twenty-four hours. The plant, of which a diagram is given in Fig. 3, comprises (1) a coke-fired furnace, a gas-mixing chamber, and a reheating chamber; (2) a revolving retort tube containing loose breakers, an automatic feed valve, an end chamber with diaphragm gland, and an automatic discharge valve; and (3) a dust remover, a condenser, a booster and governor, a gas-scrubbing plant, a meter, and a holder.

The retort is a mild-steel lap-welded tube 25 ft. long and 2 ft. 6 in. in diameter, rotating in a horizontal position within the heated brickwork chamber. The retort contains metal breakers, usually five in number, each about 20 in. in diameter; they are not fixed in any way, and different types of breakers are used, depending on the nature of the material being carbonized. A ring resting on eight steel rollers, four at each end, carried on spindles revolving in bearings, is fitted at each end of the retort tube, external to the heating chamber. The retort is driven from the charging end by means of spur gearing, the source of power being a 2-hp. motor. The automatic feeder, driven direct from the retort, is mounted at the feed end. Adjustment of this feeder insures a uniform flow of material to the retort.

The products were a residue after carbonization, gas, spirit from the gas, tar, a mixture of residue, dust and heavy tar, and ammoniacal liquor.

The residue contained 64. 8 per cent of carbon, 25.5 per cent of

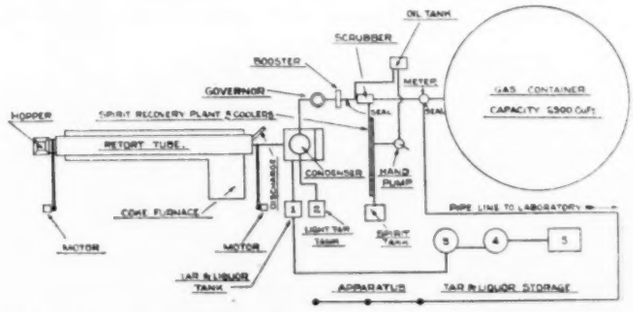


FIG. 3 DIAGRAMMATIC ARRANGEMENT OF THE FUSION-PROCESS LOW-TEMPERATURE-CARBONIZATION PLANT

ash, and 9.7 per cent of volatile matter. It had a calorific value of 10,850 B.t.u. per lb., and would, it is said, make a good pulverized fuel if properly ground. It is, however, too small for use in an ordinary furnace as it is discharged.

The gas yield was 2740 cu. ft. per ton of coal, and it had a calorific value of 1070 B.t.u. per cu. ft. It contained a rather large proportion of nitrogen, probably on account of air leakage through the feed hopper.

By scrubbing the gas with American gas oil, 3.75 gal. of crude spirit were obtained for every ton of coal gasified, but this amount would of course be reduced in refining the spirit. Its calorific value was 19,870 B.t.u. per lb., and its specific gravity 0.740.

The coal used during the test was run-of-mine Welbeck cannel mixed with some bituminous coal. It had a heating value of 12,970 B.t.u. per lb. It was found that the most satisfactory results were obtained if water was added in sufficient quantity to bring the moisture up to 5 per cent.

Three classes of tar were obtained having specific gravities of 0.815, 0.943, and 0.983, respectively. The total yield was 50.23 gal. per ton, or 72.5 per cent of the assay yield. It is suggested, however, that the yield could be increased to 54.41 gal. by slight modifications of the retort. The lighter tars could be made to give up 2.69 gal. of spirit per ton of coal. The total pitch in the mixed tar was 131.6 lb. per ton of coal.

The mixture of residue and heavy tar was more or less accidental and would not collect in an improved plant, so need not be considered here. The tar it contained is accounted for in the yield of 54.41 gal. given above.

The liquor from the various seals and that extracted from the oil were mixed together and were found to contain 2.98 lb. of pure ammonium sulphate per ton of coal. (*The Engineer*, vol. 142, no. 3699, Dec. 31, 1926, pp. 604–605, *d*)

HYDRAULIC ENGINEERING

A Hydraulic Turbine with a Rotary Jet

THIS type of turbine, invented by Dr. M. Reiffenstein of Vienna, is intended to fill the gap, from the point of view of specific speed, between the Francis and the Pelton types. The principle of the turbine is as follows: The water arriving through the nozzle L, Fig. 4, flows at a into a spiral passage, of which one of the faces, o, is closed, while the other, u, is provided with a circular orifice concentric with the axis z-z of the machine. Because of the fact that it is tangentially admitted at a, the water assumes in the spiral passage a gyratory movement and escapes at A in the form of a sheet, Fig. 5, capable of making a wheel run. The regulation of the output is effected by means of a flattened needle shown in Fig. 4.

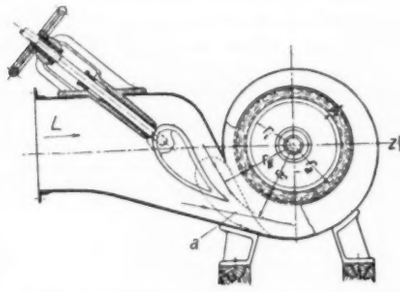


FIG. 4 GENERAL LAYOUT OF THE REIFFENSTEIN TURBINE

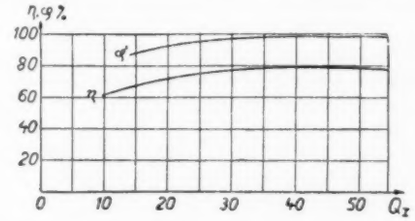


FIG. 7 EFFICIENCY OF REIFFENSTEIN TURBINE EXPRESSED IN OUTPUTS REFERRED TO HEAD OF 1 M. (3.28 FT.)
(φ = distributor efficiency; η = total efficiency.)

In tests made at the Higher Technical School in Vienna the wheel illustrated in Fig. 6 has given the efficiencies shown in Fig. 7. The conditions of operation were H = 2.5 m. (8.2 ft.), 280 liters per sec. (74 gal.), n = 180 r.p.m., n_s = 83, and P = 2.1 hp. at full load. Of particular interest is the flattened-out shape of the curve η analogous to similar curves from Kaplan and Pelton turbines. But the *specific* output [i.e., the output referred to a head of 1 m. and a wheel 1 m. (39.37 in.) in diameter] of the Reiffenstein turbine is greater than that of the Pelton wheel, because its n_s may be as high as 100. These two characteristics, economy in water consumption at partial openings and large specific output, would seem to make this

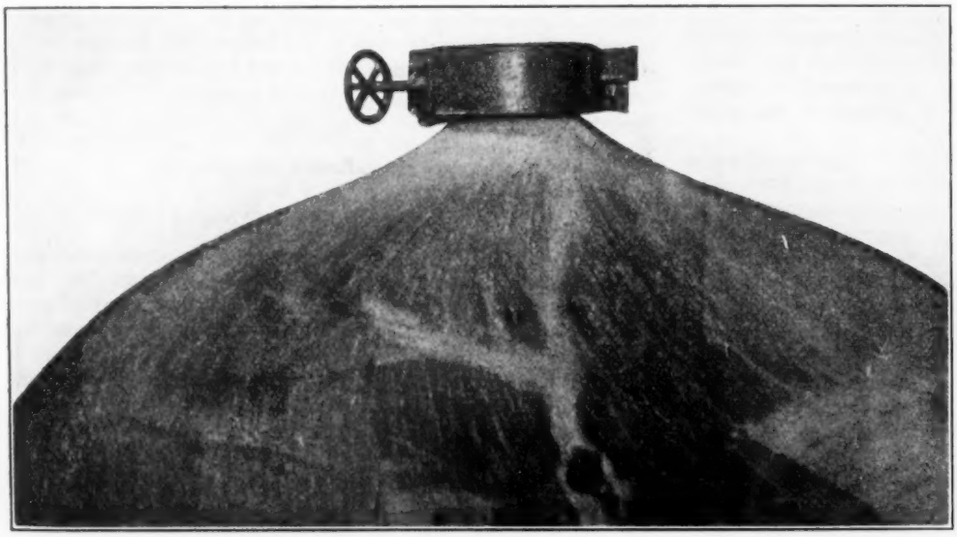


FIG. 5 WATER SHEET AS COMING FROM THE DISTRIBUTOR OF THE REIFFENSTEIN TURBINE

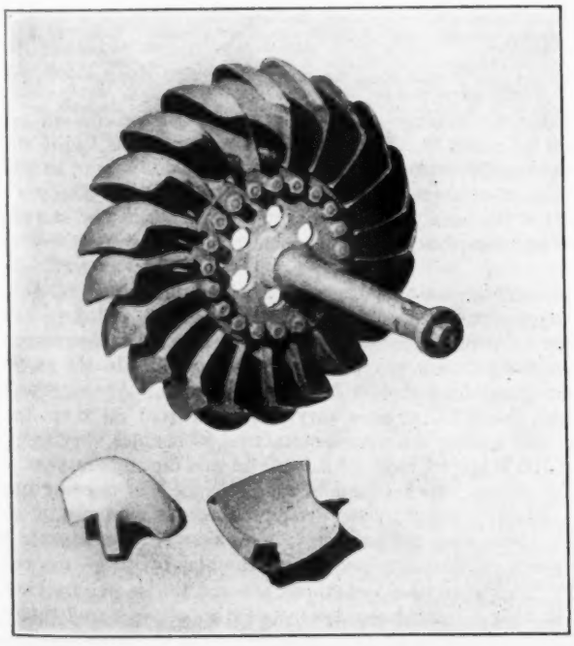


FIG. 6 REIFFENSTEIN TURBINE WHEEL

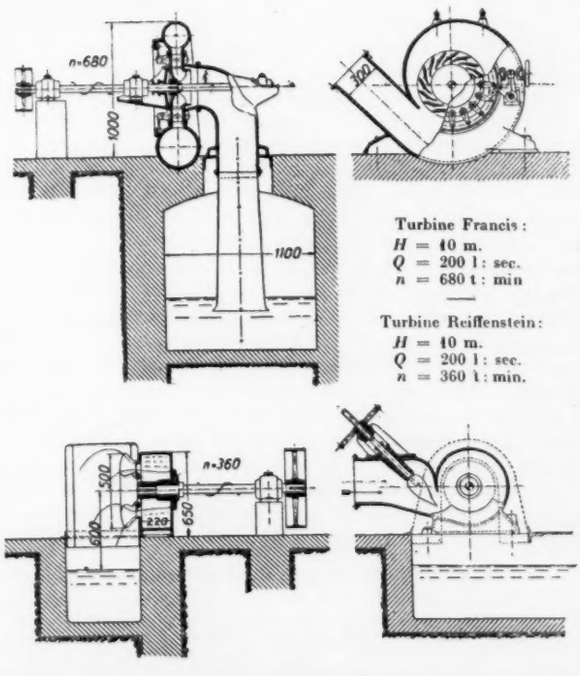


FIG. 8 COMPARISON OF FRANCIS TURBINE (ABOVE) WITH THE REIFFENSTEIN TURBINE (BELOW) FOR THE SAME HEAD AND SAME OUTPUT
(L: sec. = liters per sec.; t: min. = r.p.m.)

type of turbine particularly suitable for plants generating current for railway traction. From Fig. 8, which gives a comparison to scale of a Francis turbine with a Reiffenstein turbine, it would appear that the latter is less bulky than the former, chiefly because of the absence of the distributor ring, and because it has no delicate parts such as stuffing boxes and guide blades exposed to the possibility of corrosion and creating losses through friction. An estimate has been made giving an economy in favor of the Reiffenstein turbine as compared with the Francis of 25 to 30 per cent.

As regards the Pelton turbine, the advantage of the new type is mainly in the fact that the n_s is higher, which permits a greater specific output, but for values of n_s up to about 57 the Pelton type need not fear competition from the new type. (A. Gratzl in *Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereines*, vol. 78, no. 43/44, Oct. 29, 1926, and in *Bulletin Technique de la Suisse Romande*, vol. 52, no. 25, Dec. 4, 1926, pp. 307-309, 6 figs., *d*)

INTERNAL-COMBUSTION ENGINEERING

Investigation of the Efficiency of Diesel Engines

The author claims that previous formulas for theoretical thermal efficiencies of internal-combustion engines are based on ideal closed cycles in which the working medium is supposed to remain engaged quantitatively and qualitatively throughout the entire period of the cycle.

In the cylinder of a Diesel engine and other internal-combustion engines, however, the working medium does not remain unchanged quantitatively or qualitatively. The expanding medium in the working stroke has a different quantity and quality from that of the medium in the compression stroke. The working medium therefore does not pass through an ideal closed cycle in the cylinder.

The author treats in this paper of the theoretical thermal efficiencies of actual cycles which seem likely to take place in the Diesel-engine cylinder. He has worked out the following: (1) New formulas for theoretical thermal efficiencies; (2) comparison of thermal efficiencies in the airless-injection engine and the air-injection engine under the new theory; and (3) comparison of thermal efficiencies of various cycles based on the new theory.

He refers in conclusion to some experiments which have been carried out with Diesel engines to verify some of the theoretical propositions made by him, and to the method of finding the best conditions for the complete combustion of fuel oil with the solid-injection system, which may, according to his reasoning in Art. 8, give better overall efficiency than the air-injection system, if the combustion efficiencies of both are equal.

The author then proceeds to the deduction of general formulas for theoretical thermal efficiencies of actual perfect cycles. This part of the article is not suitable for abstracting. The same applies to the part dealing with formulas for the theoretical thermal efficiencies of ideal cycles. Formulas are next developed for specific heats of working fluids. Tests were made on solid-injection four-cycle Diesel engines and the results checked by the author's formula. These tests had to deal, among other things, with timing as related to the fuel consumption, and it was found that, keeping the other conditions unchanged, the fuel consumption decreases and the maximum pressure increases as the timing is accelerated, also that the thermal efficiency is increased when the maximum pressure is being increased. The effect of the bore, size, and shape of nozzle holes was likewise investigated. Tests were also made with solid injection. Actual examples of nozzles are given in Table 1.

To use solid injection satisfactorily, it is necessary to pulverize the fuel oil as finely as possible, and at the same time to produce a spray with sufficient penetration to insure that the fuel is brought in contact with the air required for its combustion. As the best conditions to satisfy the above requirements, the author has found from the experiments that:

1 The fuel pressure should not be below 4000 lb. per sq. in.

2 The number and size of the holes in a sprayer depend on the mean pressure in the fuel-injection system; on the viscosity of the fuel; on the mean indicated pressure aimed at; on the distance the jets have to penetrate into the combustion chamber and also on the speed of the engine; the angle of the holes, i.e., the angle of cone on which the holes are drilled, is dependent on the shape of the combustion chamber. All of the above engines are of the four-cycle, high-pressure, solid-injection type, the designed fuel-injection pressure being 4000 lb. per sq. in.

3 The shape of the combustion chamber should have the least cooling surface and the greatest distance for fuel to penetrate, and be free from sheltered narrow spaces or pockets where the fuel mist can hardly reach.

4 The timing of the fuel-valve opening depends on the number and size of the nozzle holes, shape of the combustion chamber, shape of the fuel cam, viscosity of the fuel oil, maximum pressure of combustion aimed at, and the speed of the engine.

5 The shape of the fuel cam should be one that will produce a combustion at constant pressure and maintain the maximum pressure aimed at, which should be equal to the compression pressure for the slow-speed long-stroke engine and 1.2 to 1.6 times the compression pressure for the high-speed short-stroke engine. (Mituyosi Ino, in *The Journal of the Society of Mechanical Engineers, Japan*, vol. 29, no. 115, Nov., 1926, text pp. 619–691, and illustrations pp. 672–675, of which two pages are indicator diagrams, *te*)

TABLE 1 ACTUAL EXAMPLES OF NOZZLES

B.hp.	No. of cylinders	Cylinder diam.	Stroke	R.p.m.	Fuel used	Specific gravity of fuel	Diam. of nozzle holes	No. of nozzle holes	Maker
90	2	11.5 in.	13 in.	360	Borneo heavy	0.945	0.016 in.	5	Mitsubishi
1200	12	14.5 in.	15 in.	380	Borneo heavy	0.945	0.018 in.	7	Mitsubishi
100	12	14.5 in.	15 in.	380	Shale	0.86	0.016 in.	5	British Navy
65	2	250 mm.	370 mm.	300	Galisol	0.87	0.30 mm.	5	Hesselman
300	4	380 mm.	540 mm.	220	Galisol	0.87	0.45 mm.	5	Bofors
600	6	18.25 in.	27 in.	150	Borneo heavy	0.945	0.019 in.	6	Vickers
1250	6	24.5 in.	39 in.	118	Borneo heavy	0.945	0.020 in.	10	Vickers

Report on Heavy-Oil-Engine Working Costs

Statistical data collected with the view of obtaining averages of working costs over a considerable period of time. The data are presented in the form of curves and tables, and many of these are not suitable for abstracting. As much material from the report is given here as space will allow.

Taking the 37 home stations, the average engine cost per unit generated in the year 1925–26 is 0.799 d. The following statement shows the percentage value of each item of the total working cost.

Engine Cost Per Unit Generated

	Pence	Percentage of total engine cost
Fuel	0.387	48.40
Lubricatiing oil	0.057	7.13
Water (including treatment)	0.011	1.38
Stores	0.007	0.88
Wages (running staff)	0.200	25.10
Repairs and maintenance	0.137	17.11
	0.799	100.00

Taking the average gross calorific value of the fuel oil used at 19,500 B.t.u. per lb., the overall thermal efficiency of the 46 stations employing 177 engines, varying in size from 1125 b.hp. to 60 b.hp. and run at an average running-plant load factor of 60.1 per cent, was 24.15 per cent. This is a slightly better result, and at a slightly lower running-plant load factor, than was obtained in the previous year.

The average maintenance cost per unit generated, 0.137 d. for the home stations and 0.116 d. for the overseas stations, shows a further substantial reduction in comparison with the corresponding figures for previous years, although a slight fall in the respective annual plant load factors has been recorded. Among the home stations listed 127 engines varying in size from 50 b.hp. to 1125 b.hp. and among the overseas stations 50 engines varying in size from 100 b.hp. to 1050 b.hp. were in use during the year. The improvement in maintenance cost is being brought about by the accumulation of experience in operating methods and by increases in the average plant capacity per station combined with greater output. In the last three reports the increasing average size of engines installed has been noted, and it is satisfactory to observe that at the same time average maintenance cost has continued to fall. The de-

velopment of new types of engines of larger capacity than formerly usual necessitates the gradual solution of special problems in design, and a temporary setback in regard to this item of working cost might have been experienced, but many examples of the newer types of engine have now done a considerable amount of regular work and have given such favorable service that there is no doubt that a definite advance in oil engine development has been made. (*Diesel Engine Users' Association*, London, Report S 74, 12 pp., 2 inserts, illustrated, *p*)

The Andreau Stationary-Type Engine

THE principle of operation of the Andreau variable-stroke engine was described in MECHANICAL ENGINEERING, vol. 47, no. 4, Apr., 1925, p. 292.

The Citroën Gear Co. in France is now building an improved type of such a motor on a commercial scale. As has been explained previously, the kinematic characteristic of the Andreau motor is that the head of the connecting rod describes a sort of a deformed lemniscate curve.

The difficult question of dynamically balancing the single-cylinder Andreau motor has been solved by adding an unusual type of counterbalance on each of the crankshafts, of which this motor has two.

Tests of the new motor were carried out in March, 1926, at the Laboratory of the Conservatory of Arts and Crafts in Paris. The motor is rated at 4.5 hp. At a speed of 654 r.p.m. on the slow shaft,

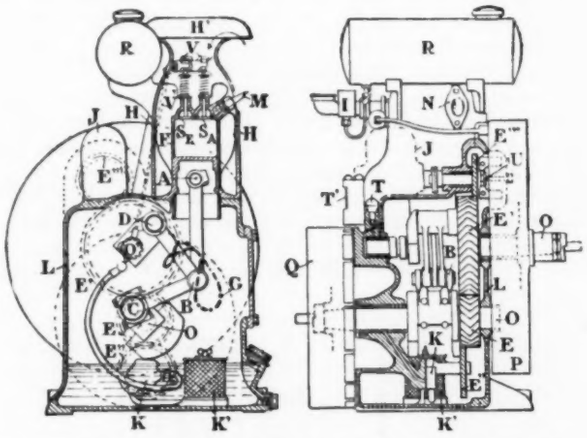


FIG. 9 VERTICAL SECTIONS THROUGH THE 4.5-HP. ANDREAU MOTOR

(*A*, axis of piston; *B*, connecting-rod head; *C* and *D*, cranks of shafts *O* and *O'*; *BC* and *BD*, double auxiliary connecting rods; *E* and *E'*, gears connecting the shafts *O* and *O'*; *E''* and *E'''*, gears operating the pump *K* and magneto *J*; *F*, cylinder; *G*, curve described by the head of connecting rod *B*; *H* and *H'*, double jacket for cooling water; *I*, carburetor; *J*, magneto; *K* and *K'*, oil pump and its filter; *L*, crankcase; *M*, spark plug; *N*, exhaust pipe; *O*, full-speed shaft; *O'*, half-speed shaft; *P*, flywheel pulley; *Q*, flywheel-section blower; *R*, gasoline tank; S_A and S_E, admission and exhaust valves; *T* and *T'*, regulator and indicator of oil pressure; *U*, speed governor; *V*, valve cams; *V'*, valve-cam rods.)

the effective power output corresponding to a minimum consumption of gasoline was 4.35 hp. This minimum consumption was 174 grams (0.37 lb.) of standard "touring" gasoline. After $3^1/_2$ hr. of continuous running the temperature of the lubricating oil was only 58 deg. cent. (136 deg. fahr.). Several other interesting features of this motor were also discovered. The size of $4^1/_2$ hp. was selected by the Citroën Co. because it is the one most desired for farm use. Fig. 9 shows sections through the Andreau motor. (*Le Génie Civil*, vol. 89, no. 23, December 4, 1926, pp. 503–504, 6 figs., *d*)

LUBRICATION

Lubrication Problems—Oiliness

IN A PREVIOUS issue of MECHANICAL ENGINEERING (vol. 42, June, 1920, p. 356) there appeared an abstract of a paper by J. E. Southcombe in which for the first time it was shown that the addition of a very minute proportion of free fatty acid to lubricating oil materially improved the lubricating properties of the latter and gave to it what is now referred to as "oiliness." This finally developed into the so-called "Germ" process now extensively applied commercially.

Another paper by the same author recently read before the various provincial centers of the Institution of Automobile Engineers (Great Britain) of necessity is intended to appeal specifically to the internal-combustion engineer, and as a great deal of work is being done by other investigators it follows that some interesting discussions are taking place. For instance, the curious feature has been ascertained that when a mineral oil has been used in the crankcase of a motor-car engine for a period of time, analysis shows it to have developed, naturally, a content of free fatty acid which, it is claimed, makes the oil as valuable as the now patented oil without the need for paying royalties for it. A very clever answer to this conundrum, however, is given by Mr. Southcombe. It is, in the first place, that if oils under these circumstances acquire this property of oiliness by the natural development of free fatty acids in them after a period of use, it emphasizes that this is the natural condition in which to use lubricating oils. Secondly, it is pointed out that while nature goes so far, it never gives what is wanted where it is wanted, how it is wanted, under the conditions it is wanted. Thus it would be obviously preferable to have something which is controlled. Moreover, it must be conceded a strong point in answer to this same criticism that in order to obtain a lubricating oil with the necessary ingredient of free fatty acid obtained in a natural way, it is incumbent upon the user to run his machine a certain time with straight mineral oil before the free fatty acids have time to manifest themselves, and in this period there is time for the bearings of the machine to be ruined. These, at any rate, are the answers to the criticisms that are being made of the Germ process of adding free fatty acids in controlled and minute quantities to mineral lubricating oils. It is open to any one to add free fatty acids to mineral lubricating oils in large quantities, but the inference is that such action will do more harm than good, and the whole secret appears to be not only in the fact that the free fatty acids are minute in quantity and controlled, but that they are added to the mineral lubricating oil in a particular way. This may account for the statement by one large manufacturer of motor cars that when he had himself added the free-fatty-acid material to his oil, he had not been able to achieve the results claimed for this particular process, but when he used oil from the patentees containing the free fatty acid, then the claimed results were obtained.

Other recent work by Ricardo in connection with the lubrication of high-speed internal-combustion engines—although the results have not yet been published—shows that an increase of as much as 10 per cent in power can be obtained by reducing the viscosity of the oil at the same time without impairing the lubricating properties. Much of this work, however, has been in relation to racing engines of one kind and another, and it must be accepted as doubtful whether this can be adopted as a criterion for work of a commercial nature, because many of these racing and aviation engines have necessarily to receive much more frequent attention in the way of overhauls than could ever be expected to be given by the ordinary motor-car owner. However, it does indicate another line of attack upon this very intriguing problem of lubrication. One really interesting point that arises generally is that as a result of the consideration of the work of the physicists, and notably Sir W. B. Hardy, it has been demonstrated that by the use of free fatty acids under conditions of boundary lubrication, there is what is known as an adsorbed layer, quite independent of any question of viscosity, which, even when the supply of lubricant has ceased, gives lubricating properties which will enable the bearing to continue running for a considerable time without seizure.

Generally speaking, of course, boundary friction is what we have to deal with in engineering, and in an automobile it occurs in at least four forms: (1) The friction of reciprocating parts; (2) the static frictional effects of starting and stopping; (3) shock effects inherent in non-foolproof mechanism; and (4) temporary insufficiency of lubricant supply. It is in this connection that the significance of the adsorption film comes into prominence, and quite a number of cases were quoted by Mr. Southcombe in which the adoption of oil containing free fatty acids had brought about marked improvement by way of reducing the friction coefficient. Gas engines, steam turbines, cotton-spinning machinery, and other types were mentioned, and not withstanding that engineers have always given this very vexing problem much consideration and thought, it is obvious that

the revelations of chemists, physicists, and engineers during recent years have manifested how much more there is yet to be learned with regard to it. (Editorial in *Mechanical World*, vol. 80, no. 2081, Nov. 19, 1926, pp. 397–398, *g*)

MACHINE DETAILS AND PARTS

The Hauber Artan High-Pressure Metallic Packing

THIS packing consists of a series of ground cups (1) which fit into one another, forming a steam-tight seal when pressed into the bottom of the stuffing box by the gland through interposed end sealing rings (6), which latter are generally of copper wire. The

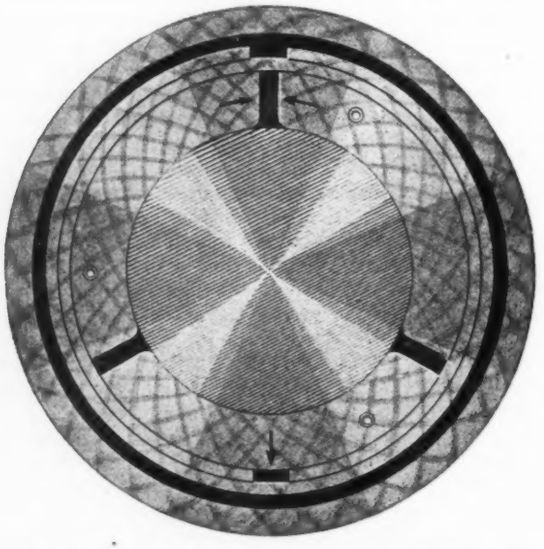


FIG. 10 SEALING UNIT OF THE HAUBER ARTAN PACKING

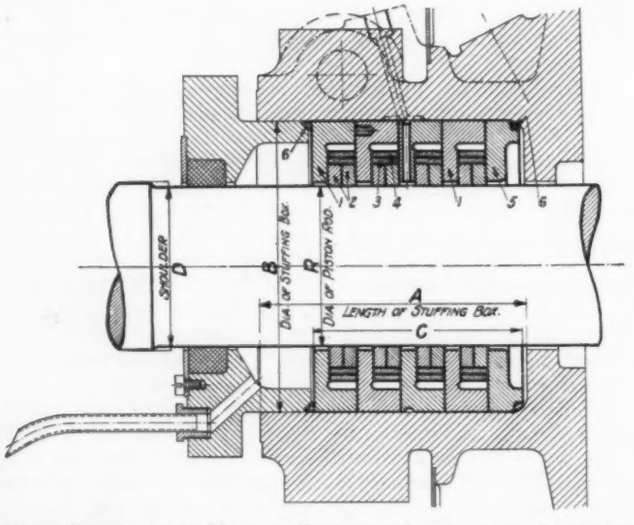


FIG. 11 HAUBER ARTAN METALLIC PACKING AS INSTALLED ON A LOCOMOTIVE

cups thus become chambers in which rest the real packing sets. The bottom cup rests against the ground ring (5), Fig. 11. The packing sets consist of two rings (2) of rectangular section placed side by side in each chamber, with two piston rings (3 and 4) covering the circumferential surface of these two sealing rings.

Each of the two sealing rings of rectangular section is split into three parts, from which are built up the pivoted units. Each of the two piston rings is split open. (Fig. 10.)

Each unit of rings is entirely free to move axially within its cup chamber and to follow the movements of the reciprocating rod which it is to seal.

The moving rod cannot therefore cause the binding of these rings, and they consequently remain tight for a remarkable length of time.

If the design were different, these rings would permit steam, or air of high pressure, to leak on to their outer surfaces. That would mean pressure on the rod and would cause constant and appreciable wear. In this construction the rings press only lightly inward with the pressure of their own spring action, so that the necessary film of lubricating oil will not be squeezed away from the rod and so that there will never be metallic contact between rings and rod. The wear of the packing is said to be slight and its life long. It is absolutely tight even with highest pressures and temperatures, because, in addition to the direct sealing action of the individual sets, there is an important "labyrinth" or "cataract" effect represented by the group of cups which would wiredraw any steam which might leak past it.

It is not necessary to have this packing specially ordered for exact rod sizes. An old rod, for instance, may be smoothed down in place where the packing of nearest size to the old rod is available; it is only necessary to bore the sealing rings (2) to the size of the smoothed rod to make the packing instantly usable. The article gives a list of locomotives of the Austrian Government Railroads on which this packing is used. It is manufactured in the United States by the Artan Co., 50 Church St., New York, N. Y. (Hans Preitner in *Lokomotivfuhrer*, Technical Section, vol. 4, no. 2, Aug. 25, 1926, pp. 7–13, *d*)

A Composite Roller-Bearing Crankshaft

THIS type of roller-bearing crankshaft was invented by Dr. Albert Hirth, who also is credited with inventing the minimeter, and is designed particularly for use with motor-car engines. It is claimed that not only is the present crankshaft suitable for mass production, but that the web is given a shape proper to take care of natural oscillation arising at high rotative speeds.

In this crankshaft, Fig. 12, both webs *a*, as well as crankpins *b*, are provided with conical teeth. The teeth in the crankpins mesh completely with those in the webs, and each gearing is provided with 24 teeth. As a result 24 different angles of engagement from zero to 360 deg. may be had and four-cylinder shafts, as well as shafts for motors with a great number of cylinders, can

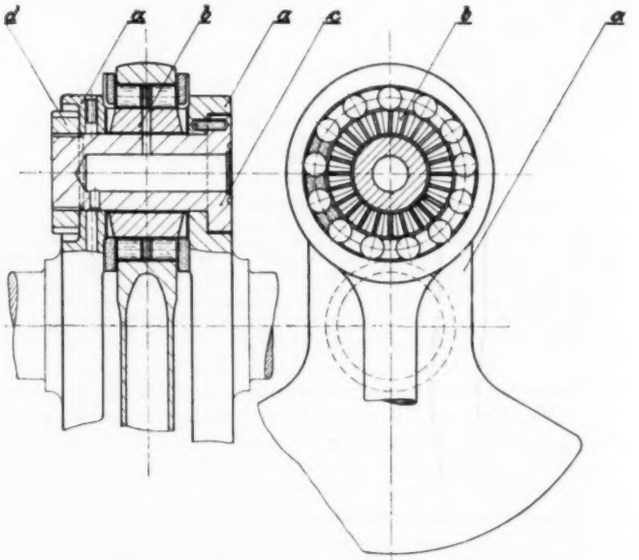


FIG. 12 HIRTH CRANKSHAFT WITH ROLLER BEARINGS FOR CONNECTING-ROD ENDS

be arranged. The gears are held together by the bolts *c* and nuts *d*.

Tests made to determine the strength and reliability of this arrangement are claimed to have shown that a crankshaft assembled in such a manner is just as strong as a sliding crankshaft of the same external dimensions. To attain this result it is necessary that the teeth be cut with the utmost precision and those on the pins be hardened and ground. The division of the teeth must be absolutely correct and the teeth faces must have absolutely correct angles exactly meshing with each other.

The bearings shown in connection with this shaft consist of a cylindrical roller bearing of a particular type. This applies particularly to the connecting-rod bearing. Such a bearing is at all times exposed to complicated forces. Each of the rollers runs in cylindrical frames and is affected in all directions by centrifugal forces. Furthermore, each roller in a connecting-rod bearing must be capable of varying its velocity at all times, as this is necessary in view of the oscillating motion of the connecting rod. Also the roller cage is exposed to particularly violent inertia forces, because of the variations of velocity referred to above.

In the roller-bearing construction designed by Dr. Hirth, comparatively small and hence light rollers are carried in very light cages. Bronze disks at both ends locate the axial position of the bearing and also help to conduct away the heat. The lubrication is effected from the inside outward through the crankpins directly on to the path of the rollers, while hardened and ground connecting-rod ends constitute the exterior race of the connecting-rod bearing.

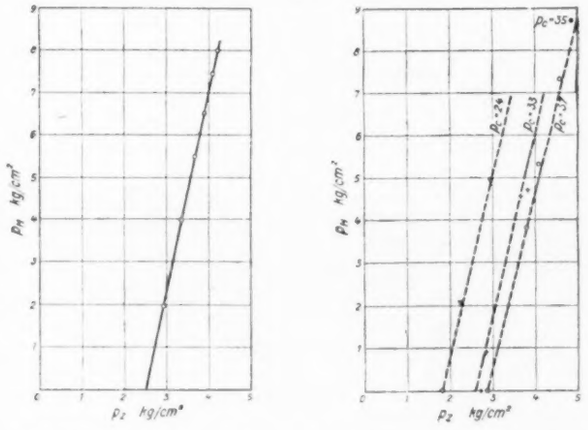
It is claimed that crankshafts made in the above-described manner have been tested successfully in continuous running at speeds of 5200 r.p.m. In one of the German automotive factories three shafts of this kind have been running for two years without any trouble. In one of the test runs the connecting rod got caught on a piston bolt and went through the engine cylinder. When the motor was being overhauled it was found that the crankshaft had not suffered in the least, although it was supported on only two bearings distant not less than 450 mm. (17.7 in.) apart, and between those bearings there were four connecting rods working on it. (Dr. Albert Hirth in *Der Motorwagen*, vol. 29, no. 34, Dec. 10, 1926, pp. 851–852, 1 fig., *d*)

MEASURING INSTRUMENTS

Indicator of Average Pressure or p_1 Meter

THE author claims that mechanical engineering does not possess an instrument, such as the ammeter or wattmeter in electrical engineering, which will permit the direct reading of engine output. The apparatus here described is intended to fill this need. Its purpose is to show at any instant the average pressure prevailing in the cylinder of a reciprocating machine of any kind whatsoever. This would, of course, also permit recording this average pressure over a period of time, and such a curve would give a clear and precise picture of the total output of the engine. The working of the apparatus is based on a newly discovered recognition of the fact that in nearly all reciprocating-piston engines there is a surprisingly simple functional relation between the average pressure referred to time and the average pressure referred to the piston stroke. The following will explain this more precisely. Fig. 13 shows a series of diagrams drawn for a conventional non-condensing steam engine working with various cut-offs. The drop of pressure at admission and the throttling at exhaust have purposely been left out of consideration here in order to obtain diagrams determined exclusively by the valve setting and the thermodynamic behavior of the steam. In Fig. 14 are shown corresponding diagrams of piston pressure-*time*. Fig. 15 shows average piston-stroke pressures (derived from Fig. 13 and denoted by p_H) functionally referred to the average piston-time pressures (determined as average heights from Fig. 14 and denoted by p_Z). Notwithstanding the fact that the cut-offs varied to an extraordinary degree (from 10 to 60 per cent), the individual values lie almost exactly on a straight line starting from a point located at a certain distance from the zero point. Diagrams with very considerable throttling at admission and exhaust have shown a similar general behavior. Such a straight-line functional relation may be expressed in the form of an equation, and, for example, for the case of Fig. 15, the following equation holds good.

$$p_H = 4.76(p_Z - 2.48)$$



FIGS. 15 AND 16 AVERAGE PRESSURES REFERRED TO PISTON STROKE (p_H), AS A FUNCTION OF AVERAGE PRESSURE REFERRED TO TIME (p_Z) FOR A NON-CONDENSING STEAM ENGINE (LEFT) AND 4-STROKE CYCLE DIESEL ENGINE (RIGHT)

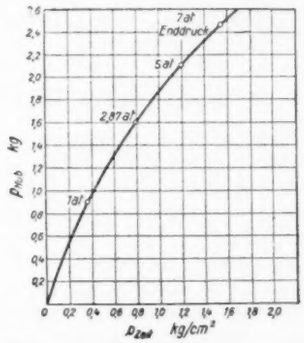


FIG. 17 AVERAGE PRESSURES REFERRED TO PISTON STROKE AS FUNCTION OF AVERAGE PRESSURES REFERRED TO TIME FOR VARIOUS END PRESSURES IN COMPRESSORS

(D_{Zeit} = D_{time}; *at.* = atmospheres gage; *enddruck* = end pressure.)

FIGS. 13 AND 14 PISTON PRESSURE-STROKE DIAGRAM AND PISTON PRESSURE TIME DIAGRAM OF AN ORDINARY NON-CONDENSING STEAM ENGINE FOR VARIOUS CUT-OFFS

An investigation along the same lines—but for other types of reciprocating piston engines—of the relation between the average piston-stroke pressure (p_H) and piston-time pressure (p_Z) has shown that in nearly all cases a straight-line relation obtains. This relationship has been investigated with care in the case of Diesel engines, and among other things learned was the influence of the various compression levels and particularly the influence of the various rates of combustion (strong after-burning, pronounced preignition).

A large number of values based on indicator diagrams are shown in Fig. 16 and cover the case of four-stroke cycle Diesel engines with special consideration to extreme values, such as values for compressions of 24 atmos. or 37 atmos. The values obtained under conditions where the compression was the same are connected by broken lines. These show at once that the values obtained with a given compression lie exactly on a straight line, even though the average indicated pressures may vary from zero to 8.35 atmos., and further that the straight-line relationship obtains notwith-

standing great variation in the way combustion takes place. When compression changes a similar and parallel line is obtained.

The author derives the following formulas, the first being for determining the average piston-stroke pressure for the average piston-time pressure for two-stroke-cycle oil engines.

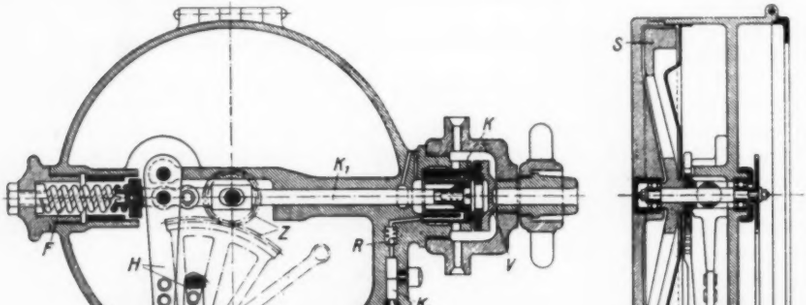


FIG. 18 THE GEIGER p_i METER

$$p_H = 8.5\ (p_z - 0.0811 p_c)$$

For four-stroke-cycle engines,

$$p_H = 4.25(p_z - 0.0811 p_c)$$

where p_c is the end pressure in compression.

For a given compression (which does not vary during operation) the formulas are quite similar and, for example, for a compression pressure of 32 atmos. in a two-stroke-cycle engine the following is obtained:

$$p_H = 4.25(p_z - 11)$$

As regards pumps, it is clear at once that the relationship of the average pressure referred to time to the average pressure referred to the stroke may be represented by a straight line passing through the point of origin.

In the case of compressors the relationship between the two kinds of pressures was carefully investigated within a wide range of pressure variations. If atmospheric air is taken in at the suction and compressed to levels in a single stage, one obtains the curve shown in Fig. 17. Here it would appear that while this curve is not a straight line, nevertheless within the ranges of pressure particularly used in compressors it may be replaced by a straight line for all practical purposes. Should it happen that a compressor were actually built such that the end pressure would vary from zero to 8 atmos. or more, it would be perfectly feasible to represent the functional relationship of the average stroke pressure to the average time pressure on a scale in such a manner that here also it would become possible to read the average stroke pressure from an instrument so built as to indicate the average pressure referred to time.

From the above it would appear that for a given type of reciprocating piston machinery or for a given set of conditions there is always a very simple relationship between the average piston pressure referred to stroke and the average piston pressure referred to time. If the latter is known, it is quite easy to find the former, and hence the instantaneous output of the machine. From this the author proceeds to describe his apparatus and begins by claiming that it is possible in a comparatively simple manner to determine the average piston-time pressure. The present pressure diagrams refer to time, and apart from the line of average pressure consist of a series of superimposed sinusoidal periodic curves of various frequencies which can be averaged by harmonic analysis. If an indicator be designed in such a manner that its natural frequency lies way below the frequency of these periodic forces, it will not affect them and the piston will automatically occupy a position corresponding to the average pressure.

In Fig. 18 the piston K acts through a piston rod K' and transmissions H and Z (lever or gear) having a very large ratio of transformation, on flywheel S which actuates directly the pointer Z_1. Spring F, which is of the same type as those used in indicators, generally holds the piston in the position of equilibrium for any average pressure that may prevail. This represents the general principle of the device, and there can be many refinements. Thus, instead of having the pointer actuated from the flywheel, tomorrow a transmission may be introduced between them to increase the motion of the pointer and make it possible to read it from a distance. The apparatus gives the pressure-time relation, but it is perfectly feasible to add a pressure-stroke scale which would permit reading this latter directly. This pressure-stroke scale will, however, vary for various kinds of engines tested. The author describes also several other refinements such as methods of applying this indicator to engines running at a very slow speed, methods of preventing gases leaking past the piston to affect the indicator, etc.

The apparatus is built by Lehmann & Michels, Hamburg, Germany. (Dr. Jos. Geiger in *Schweizerische Bauzeitung*, vol. 88, no. 21, Nov. 20, 1926, pp. 281–283, *d*)

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The results obtained appear somewhat complex; this, in view of the general nature of the problem, is unavoidable, but the actual computation in any particular case, although somewhat long, is not difficult. It is necessary, however, to work to a considerable degree of accuracy.

The method of solution adopted is to consider the wheel as a framework with a number of redundant reactions and to apply the Principle of Least Work to obtain the necessary equations.

The equations so far obtained are perfectly general and may be used for the determination of the stress distribution in any wheel. The arithmetical work is rather long, but further simplification of the equations does not appear to be practicable and in any case does not lessen the labor of computation.

Two cases are specially developed—that of a rigid rim and of a rigid arm. The equations obtained are of such a character that their general solution is rather long, but for any special case the coefficients are found with comparative ease and permit obtaining the practical solution. (Prof. A. J. Sutton Pippard and J. F. Baker in *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, vol. 2, no. 12, Dec., 1926, pp. 1243–1253, 4 figs., *mt*)

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A photomicrograph in the original article shows that the greatest depth of hardening is at about the pitch line, and that the effect tapers away in either direction, while the hardening does not extend to the radius at the root of the tooth. This latter feature, in itself, is of considerable value, as it has been found that with a wheel hardened *en bloc* the slightest scratch or tool mark at the root of the tooth is liable to develop into a crack, which may result in the complete fracture of the tooth. The merit of the soft core to the tooth needs no comment.

That the drastic treatment described does not result in introducing a non-coherent layer of hard steel, is shown by photomicrographs in the original article. From these it would appear that the core of the tooth is pearlite passing gradually through sorbite into martensite, the latter being toward the surface of the tooth. The transition from one stage of hardness to another is gradual, and there is no distinct line of parting.

A pinion which has been hardened by the process under review was put in service on one of the motors of a London electric tram car, but had to be taken off again as a bolt or some other loose piece had dropped in between the meshes and had badly scored the teeth. It is noteworthy, however, that not one of the teeth had been cracked away from the hub, while a large part of the material which had been displaced in making the gashes was folded back in the immediate vicinity, and indicated plainly that the ductility of the normal steel was not affected by the surface-hardening process.

The article describes in detail the apparatus employed. It is essential to the success of the process that the heating should progress continuously across the face of the tooth, and that any spot should be reheated after it is once hardened. For this reason the blowpipe is extinguished immediately after it has traversed the width of the tooth by means of an automatic trip mechanism. At the same time the nut on the traversing screw is opened, and the carriage can then be drawn back quickly by hand ready for the next tooth. It would of course be possible to provide an automatic return, but the hand arrangement is more simple.

When helical or skew gears are being hardened a templet attached to the main framing is used to guide the blowpipe. The rate of progress varies, according to the width and size of the teeth, from 20 to 30 linear feet per hour.

From the above account it will be seen that the process is purely mechanical and requires very little skill on the part of the operator. It is in this direction that the Shorter process must be differentiated from some other attempts to harden by means of a hand-controlled blowpipe, which have not been very successful. The difference lies in the fact that with a blowpipe held in the hand it is almost impossible to avoid occasionally reheating a spot already hardened, with the result that the surface is cracked and the hard skin flakes off. In the case of the Shorter hardened gears there is no indication of cracking whatever.

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It should further be noted in this connection that exceedingly promising experiments with high-speed Diesel engines for automobiles are being carried out both by the Junkers-Werke (Junkers Works) in Dessau and R. Bosch A.-G. in Stuttgart. The new Junkers engine is characterized by the employment of two pistons in each cylinder, the two pistons working in opposite directions. Prolonged experiments and tests have already proved this engine's usefulness for driving motor vehicles. The Bosch engine also has proved its worth in trials on a vehicle. Great ease of starting the engine by means of a hand lever and the smokeless working of the engine at speeds above 1400 r.p.m., are features of this engine deserving to be mentioned. (From an article by Dr. Heller, Berlin, in *Engineering Progress*, vol. 7, no. 12, Dec., 1926, pp. 323–326, 10 figs., *d*)

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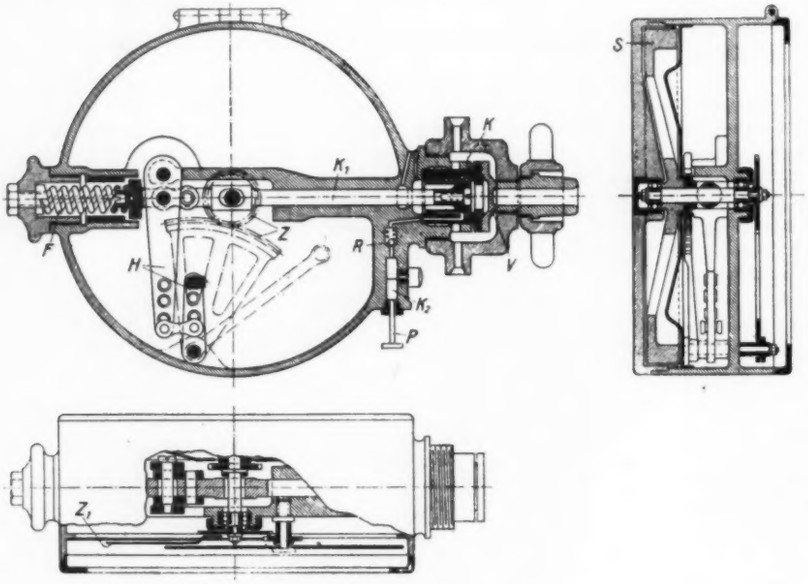

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The 5-Hp. Constantinesco Chassis

THE Constantinesco system for producing a variable torque with an ordinary engine as required by the varying conditions of car load and of road has been described in its general features in MECHANICAL ENGINEERING, vol. 46, no. 1, January, 1924, p. 47.

The "converter," as the designer calls his device, has now been designed into the engine of the car. A gear reverse is also provided. In this case the engine is a two-stroke, two-cylinder one, with the cylinders water-cooled and spaced a little apart to provide room for the inertia weights and engine flywheel. The action of the gear, which consists of only a few parts, is quite complex and cannot be described here on account of lack of space. The original article gives, however, a complete analysis with diagrams of the converter gear in its various positions.

As regards the performance of the car, it is stated that in starting away the throttle pedal is fully depressed instead of gradually as in the ordinary car. In the process of acceleration, which is rapid, there is a little vibration but it is of high frequency, and as soon as the vehicle has gathered speed the travel is perfectly smooth and there is an entire absence of mechanical noise or vibration. The maximum speed of the car is not great, probably a little under 40 m. p.h. as a maximum. This, however, constitutes a reasonable performance in view of the size of the engine. If this car is successful it may have profound influence on the design of motor cars, because of the utter simplicity of the gear and chassis and the economy of operation. (*The Automobile Engineer*, vol. 16, no. 223, Dec., 1926, pp. 474–479, illustrated, *dA*)

POWER GENERATION

Utilization of the Heat Energy of the Seas

THE proposition here described has attracted considerable attention in Europe, both on its merits and because of the standing of the authors. Of these, M. Georges Claude is well known in this country as the discoverer of the method of dissolving acetylene in acetone, as the inventor of a system of low-temperature refrigeration and of a system of producing synthetic ammonia, and in connection with the use of neon gas in electric lamps, etc.

The system of power generation here proposed is based on the well-known difference between the temperature of water in the upper layers of the ocean, which varies from 26 to 30 deg. cent. (78.8 to 86 deg. fahr.) and the temperature at a depth of say, 1000 m. (3280 ft.) which is said to be from 4 to 5 deg. cent. (39.2 to 41 deg. fahr.). Briefly, what the authors propose to do is to utilize the surface water from the sea in an evaporator connected through a steam turbine to a condenser supplied with cold water from a great depth. The intention is to utilize only a very small range of temperatures, say, 25 to about 30 deg., and to rely for the power output on the amount of steam produced under these conditions and the high vacuum created by the use of the very cold water at the condenser end. At first it would appear that the amount of steam generated under these conditions would be so very small as to be negligible. The authors claim, however, that this is not the case.

Thus, for example, steam at 0.03 atmos. pressure generated by water at 24 deg. cent. (71.2 deg. fahr.) and delivered against a vacuum of 0.001 atmos., such as can be maintained by a condenser with water at 7 deg. cent. (44.6 deg. fahr.) will have a discharge velocity of 500 m. per sec. (1640 ft.) and will give to a single-stage turbine an optimum velocity of 250 m. per sec. (820 ft.), which is quite good. Moreover each kilogram of this steam at 0.03 atmos. pressure, i.e., a pressure 700 times less than the pressure of steam at 20 atmos., will produce only five times less work than the same steam expanding from 20 atmos. to 0.2 atmos. These conclusions appeared at first sight so surprising that tests were made to determine to what extent they might be true. In these tests the disk of a De-Laval turbine, 15 cm. (5.9 in.) in diameter and designed to operate at a pressure of 20 atmos., i.e., under conditions quite different from those under which it was tested, was mounted between a flask containing 20 liters (5.2 gallons) of water at 28 deg. cent. (82.4 deg. fahr.) on one side and a vessel filled with broken ice on the other.

Next the air was exhausted by a pump, which was then shut off. As soon as the pressure fell below the vapor tension of the water, the latter began to boil violently, the steam condensing in the ice beyond the turbine. The latter then started running and attained a speed of 5000 r.p.m., driving a dynamo which brought to a bright glow three electric lamps taking 2.5 watts, the lamps going out eight to ten minutes later, when the water had cooled below 20 deg. as a result of its intense evaporation. This may be considered as a very unusual demonstration in view of the extremely poor efficiency of such a small apparatus working under such minute pressures and at speeds entirely different from those for which it was designed. What the authors propose, then, is to do this on a big scale, utilizing water from two different depths. They calculate that 5000 calories would be obtained per cubic meter of surface water, equivalent to 8 kg. (17.6 lb.) of steam, which when used between pressures of 0.03 and 0.01 atmos. will theoretically give 100,000 kg-m. (723,000 ft-lb.). Assuming an efficiency of 75 per cent and a loss of 30,000 kg-m. for pumping the warm and cold water, etc., there will remain a net power output of 45,000 kg-m. (325,350 ft-lb.) per cubic meter of water, or for 1000 cu. m. (35,314 cu. ft.) of water per sec., a total output of 400,000 kw.

If such a plant were installed somewhere in the tropics, there would be the further advantage that each cubic meter of water drawn from the depths mentioned though heated in the condenser from, say, 8 to 18 deg. cent. (46.4 to 64.4 deg. fahr.) would still be of very great value as a cooling medium. (*Comptes Rendus des Séances de l'Académie des Sciences*, vol. 183, no. 21, Nov. 22, 1926, pp. 929–933, and two notes giving credit to previous investigators in the same publication, no. 22, Nov. 29, 1926, pp. 1005–1006, *de*. Also reprinted in *La Nature*, no. 2748, Dec. 4, 1926, pp. 357–359.)

An editorial in *The Engineer* of November 26, 1926, offers the following criticism of this proposition:

"It may be interesting to look into the arithmetic of this wonderful proposal. Taking the most favorable of the authors' figures for the respective sea-water temperatures, but using fahrenheit units for convenience, we will assume the surface water to be at 87 deg. fahr. and an unlimited supply of cold water from the depths to be available at a temperature of 39 deg. fahr. We will further assume the useful heat of the warm water to be exhausted when it falls to a temperature of 78 deg. fahr. by evaporation, as in the case of the experimental model. Each pound of warm water, therefore, before being rejected would part with 8.97 B.t.u. and it would require over 116 lb. of water to pass through the boiler to supply enough heat to produce 1 lb. of steam by evaporation. The steam produced would have an average pressure of about 0.55 lb. per sq. in. abs., so that the "boiler" would have be working under the conditions of a condenser with something like 28.9 in. vacuum. The actual condenser, supplied with cooling water at 39 deg. fahr., could not possibly have a vacuum exceeding 29.96 in., corresponding to an absolute pressure of 0.117 lb. per sq. in. Working between these pressures, an ideal turbine working on the Rankine cycle would have a theoretical steam consumption of practically 40 lb. per kw-hr. Assuming, as the authors do, that a machine could be built with an efficiency of 75 per cent for such conditions, we arrive at a figure of 53 lb. per kw-hr. What kind of thing the turbine would be we can leave to the imagination. As the steam with which it works would have a volume of about 580 cu. ft. per lb., it would require a steam pipe over 23 ft. in diameter to supply a 10,000-kw. turbine, assuming as high a steam velocity as 200 ft. per sec. to be employed. Boilers, condensers, and turbines would all be proportionally enormous, and the impossibility of maintaining a vacuum of 29 in. or more in such a system is sufficient to demonstrate the utter futility of the proposal. If Messrs. Claude and Boucherot can really find a practical way of producing energy from water at 87 deg. fahr. by the use of water a few degrees colder, there is ample scope for them to utilize the discharged circulating water from some of the power houses in Europe before developing the tropical seas." (*The Engineer*, vol. 142, no. 3698, Nov. 26, 1926, pp. 584–585.)

POWER-PLANT ENGINEERING

Westinghouse 104,000-Kw.-Capacity Turbine and Combination Turbine

THE first-mentioned turbine, Fig. 19, is a combination cross and tandem compound machine consisting of a high-pressure turbine driving a 55,000-kw. main generator and a 4000-kw. house generator at 1800 r.p.m., and an intermediate- and a low-pressure turbine in

tandem driving a 45,000-kw. main generator likewise at 1800 r.p.m.

The unit is designed for reheating, the steam being taken from the high-pressure-turbine exhaust at approximately 41 lb. abs. and dry and saturated to a tubular reheater placed in front of the intermediate-pressure unit and passing thence to the intermediate-pressure inlet at 500 deg. fahr.

One of the chief features of interest is the disposition of the steam flow in the intermediate- and low-pressure turbines. These turbines are arranged on the "divided-flow" principle, which has already found application in certain marine installations. The intermediate-pressure turbine is of the semi-double-flow construction, in which the steam flowing toward one end (about one-third of the total) passes through sufficient stages of blading to be exhausted at the final condition of two vertical condensers, while the other two-thirds of the total steam flow pass through fewer stages of blading, to be carried thence by a receiver pipe to the inlet of the low-pressure turbine. The low-pressure unit is also of the double-flow construction and exhausts into four vertical condensers.

The reduction in last-row annulus due to the subdivision of exhaust area afforded by the divided-flow arrangement makes it possible to

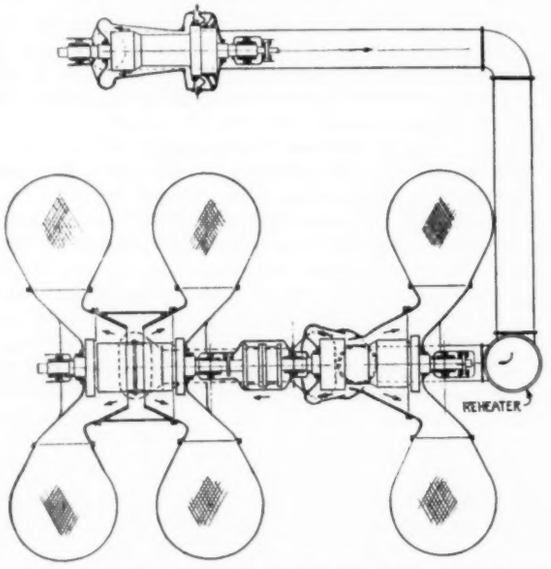

FIG. 19 PLAN VIEW OF 104,000-KW.-WESTINGHOUSE TURBINE

operate the intermediate- and low-pressure units at 1800 r.p.m. It has been found possible to dispense with the blade-ring construction, all the stationary blading being carried in the cylinder proper. The resultant simplification of the cylinder construction is accompanied by a considerable reduction in the unit turbine weights. This tends to offset to some degree the increase in weight due to the addition of the intermediate-pressure turbine, inasmuch as the low-pressure turbine, if it took the entire steam flow, would have to be a 1200-r.p.m. machine because of last-blade-row limitations.

Among new designs which have made their appearance in the past year is a combination impulse and reaction turbine from which all the steam is bled from the impulse-wheel chamber into a high-pressure process-steam line, while steam from a low-pressure line is bled back into the reaction stage of the turbine in sufficient quantity to enable the unit to carry the load. Both outward and inward bleeding are automatically controlled and in addition a bypass is provided, controlled by an automatic valve connected to the governor system. In case of lack of low-pressure steam to feed the reaction portion of the turbine, this valve bypasses enough steam around the diaphragm to satisfy the turbine load condition.

The latest development in surface condensers is the employment of a flexible metal diaphragm between the tube sheet and condenser shell. This eliminates the sliding head with its attendant sealing difficulties and permits tubes to be rolled at both ends and still expand freely without disturbing the water-tight integrity of the shell and tube-sheet connection. (From an article on Developments in Steam Turbine Practice, by J. D. Schmidt, Westinghouse Electric & Mfg. Co., So. Philadelphia Works, in *Power Plant Engineering*, vol. 30, no. 24, December 15, 1926, pp. 1320–1321, 1 fig., *d*)

WELDING

Experience in Welding Structural Steel

THE author is an engineer of the Lincoln Electric Co., Cleveland, Ohio, and states that up to the present about 15,000 tons of steel have been fabricated in the plant of his company entirely by welding, the purpose being to produce from structural-steel pieces substitutes for the gray-iron castings used for machine bases, frames, and parts. Other manufacturers, with the coöperation of this company, have done probably twice as much welded fabrication to replace gray-iron castings. The essential facts of their experience as well as that of the Lincoln Electric Co. were available to the author, and the results developed from this experience are as follows:

1 The metallurgical limitations of welding must be taken into consideration in the design of a welded joint.

2 Joints must be designed for welding; adaptation of welding to riveted design is not satisfactory from the cost point of view.

3 The company has not had a weld fail which was designed by its engineering department and made under its own supervision.

4 The average cost of the welding per ton of steel was under $20, this figure including the assembling and welding labor, electric power, and welding rod.

5 The material saved as compared with riveting averages about 20 per cent.

6 No saving has been made in supervision and inspection; the work must be done by high-grade men under competent supervision.

7 A considerable part of the work has been done on piece-work rates, with advantages from the cost point of view and entirely safe.

The extent to which these facts apply to the welding of structural steel for buildings may be subject to some difference of opinion. The object was not to prove that welding should be used in place of riveting in building construction, but rather to develop facts. However, it may be of interest to state the company's own conclusions.

Based on the experience of turning out some 45,000 tons of steel fabricated entirely by welding, the author concludes:

1 Welding structural steel for buildings may be done safely in the shop under proper engineering design, competent supervision, and competent inspection.

2 Under shop conditions there is a possibility of saving about half the labor required for riveting in many cases; on some classes of work there would be no labor saved. No estimate can be made at this time on what the average labor saving would amount to for any given period due to the wide variation in the nature of the work.

3 The material saving will depend entirely on particular circumstances, and no general estimate can be made. It appears reasonable to assume that material savings can be made, perhaps of the same order as those actually made in the work described (20 per cent).

4 The economy of field welding in the erection of building structures is open to question at the present time, except where noise elimination is a determining factor. Further developments may be expected, showing the economy of welding.

5 The economy of field welding in the repair or alteration of existing steel structures or buildings is certain. Very large labor economies may be shown in this direction.

In view of the above conclusions the author believes that the application of electric arc welding to the fabrication of steel for buildings has been carried about as far as the manufacture of welding equipment can carry it. Welding, he states, has been shown to be safe and economical in many cases, and the opportunity is at hand for large steel-fabricating concerns to turn this experience into working practice. (Robt. E. Kinkead, Engr., Lincoln Elec. Co., Cleveland, Ohio, in *Engineering News-Record*, vol. 97, no. 26, Dec. 23, 1926, pp. 1033–1034, illustr., *p*)

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general; *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

The Conference Table

THIS Department is intended to afford individual members of the Society an opportunity to exchange experience and information with other members. It is to be understood, however, that questions which should properly be referred to a consulting engineer will not be handled in this department.

Inquiries will be welcomed at Society headquarters, where they will be referred to representatives of the various Professional Divisions of the Society for consideration. Replies are solicited from all members having experience with the questions indicated. Replies should be as brief as possible. Among those who have consented to assist in this work are:

ARCHIBALD BLACK,
Aeronautic Division
H. W. BROOKS,
Fuels Division
R. L. DAUGHERTY,
Hydraulic Division
JAMES A. HALL,
Machine-Shop Practice Division
CHARLES W. BEESE,
Management Division
G. E. HAGEMANN,
Materials Handling Division
J. L. WALSH,
National Defense Division
L. H. MORRISON,
Oil and Gas Power Division
W. R. ECKART,
Petroleum Division
F. M. GIBSON and W. M. KEENAN,
Power Division
WINFIELD S. HUSON,
Printing Machinery Division
MARION B. RICHARDSON,
Railroad Division
JAMES W. COX, JR.,
Textile Division
WM. BRAID WHITE,
Wood Industries Division

Aeronautics

Aerial Surveys[1]

A-9 To what extent can aerial surveys be used to determine elevation contours in right-of-way studies? What degree of accuracy is attainable?

In addition to the remarks of E. R. Polley on this subject in the January, 1927, issue of MECHANICAL ENGINEERING, the writer would say that from the standpoint of micrometrical observations, no obstacle is presented seriously to interfere with expeditious and accurate determination and delineation of elevation contours directly by means of aerial photographs. The method is known as the parallax method, and there are various ways and appliances for utilizing it. The difficulties are, in the order of greater importance: First, the insurance against distortion of detail in horizontal planes on the earth's surface, because there is now no known method either of maintaining the sensitive surface truly horizontal during exposure, or of rectifying a tilted picture without resorting to ground controls; second, uneven and generally unknown expansion and contraction of photographic material, even on plates; third, distortion due to lens aberrations—this can be corrected for, but such corrections are tedious and expensive; obscuration of the ground by natural cover, necessitating estimation of the height of such cover; lack of photographic detail on the ground itself, although this is very seldom serious.

However, aerial photographs have been used in plane table and cross-section sheets with considerable saving of cost and increase of accuracy over the usual ground-survey methods. Very few except horizontal measurements are made, only sufficient to determine the scale of each photograph on some one horizontal plane, or contour; and in transference of detail to map material, all distortions producing discrepancies over the allowable error are corrected. One of the greatest uses of aerial photographs is in connection with the stereoscope, as already pointed out by Mr. Polley. (E. H. Corlett, Engineering Manager, Fairchild Aerial Camera Corporation, New York, N. Y.)

Helicopter Problems

A-10 What are the outstanding problems to be overcome in developing a successful helicopter?

To the writer, as an airplane pilot, it seems that the main problems in the development of a successful heliocopter are attainment of stability and control, the ability to descend safely in the event of motor failure, and some responsible degree of efficiency per horsepower expended. (Richard H. Depew, Jr., Vice-President, Fairchild Flying Corporation, New York, N. Y.)

Machine-Shop Practice

Fitting a Loose Pulley to a Shaft[1]

MS-5 The bore of a pulley is too small to accommodate the shaft upon which it will run loose. Is it recommended that the cold-drawn shaft be turned to fit, or is it better to rebore the pulley and thereby preserve the hardened "skin" of the shafting?

(*a*) Referring to the discussion of this question in the January, 1927, issue of MECHANICAL ENGINEERING, the writer does not entirely agree with Professor Turner's reply, as it is true in a limited number of cases only and does not take into consideration features often of more importance in deciding the proper course to follow. If the shaft is already centered, it is probably true that it is easier to turn it down to fit the pulley bore; otherwise, it is probably easier to chuck the pulley true and bore out the hole. Further, if the loose pulley comes between bearings and the shaft is turned down, at least one of the bearings must be refitted. The most important consideration from the user's viewpoint is keeping the shafting diameters standard, that is, within the limits of accuracy usual with cold-rolled shafting. Then, in the event of a breakdown or in the course of overhaul, shafts can be replaced by pieces cut from standard lengths very quickly and the machine will not be idle for long periods while shouldered or odd-diameter shafts are turned. Further, pulleys, bearings, and bushings can be fitted more quickly, as even a small shop can carry the dozen or so reamers covering the sizes in frequent use and can borrow the occasional one for an odd job. If the shafting is oversize and the pulley bore is right, it is probably cheaper to buy a standard piece and stock the odd size until some special job is encountered. (H. D. Fisher, Plant Engineer, New Haven Pulp & Board Co., New Haven, Conn.

(*b*) Rebore the pulley to maintain the shaft strength, to obtain greater bearing area on the shaft, and to follow the principle of removing metal from the member carrying the lowest stresses. (L. H. Roller, Engineer, Linde Air Products Co., New York, N. Y.)

Management

Code of Best Practice[1]

MG-2 What have been the observations and experiences of members in the matter of time studies, and what opinions have been formed regarding the advisability or possibility of evaluating the various factors involved, looking toward the development of a "Code of Best Practice?"

(*a*) There are few looser terms in use today in the field of shop management than "time study." It is applied to the description of anything from the crudest observation of overall time to the most elaborate analyses, and many of the latter are quite valueless because certain essential considerations have been overlooked or ignored in making them. As to allowances, the writer questions whether anything of value can be evolved that will enable a formula to supersede careful judgment applied to the individual situation, yet this essential judgment could be materially assisted by a knowledge of the limits and the laws of variation between them, as developed from general practice on the same operations. Such data would have little value, however, unless they represented an extremely wide field of observation. At the present time, it is not possible to open up a field sufficiently wide for its results to be measurably authentic. This is because there is nothing approaching standard practice or, more accurately, best practice. (T. D.

[1] This subject has been discussed in a previous issue.

Nevins, Miller, Franklin, Bassett & Co., Industrial Engineers, New York, N. Y.

(*b*) The fundamental difficulty in time study is that it is not possible to make accurate determinations and measurements with the same degree of certainty that we make laboratory experiments. At the best they must be approximate, having in mind the fact that we are dealing with human beings. The writer questions whether it will ever be possible, therefore, to set up any system of allowances that will lead to accurate determinations. (Dexter S. Kimball, Dean, College of Engineering, Cornell University.)

(*c*) A survey of methods of time study in use and an attempt to evaluate the results should prove very serviceable. There would be difficulty, however, in getting anything at all complete, as there are few people who have any idea as to what is being done in the field. All the more reason for getting started. (Lillian M. Gilbreth, President and Treasurer, Frank B. Gilbreth, Inc., Montclair, N. J.)

Power

Combating Scale Formation

P-1 In the endeavor to prevent scale formation in boilers, which readers have found most desirable as regards ultimate economy, the use of boiler compounds or the treatment of the feedwater before it enters the boiler?

Except in small plants, chemical treatment of the feedwater before it enters the boiler is preferable to the use of boiler compounds. Chemical treatment can be designed to meet the requirements of the particular water used in a plant. No doctor can prescribe the same pill for all patients, and neither will a patented boiler compound be satisfactory with all kinds of water. (H. L. Solberg, Instructor in Mechanical Engineering, Purdue University.)

Welding Industrial Piping

P-2 In the welding of power and industrial piping, what types of joints are recommended for the various classifications of lines, pressures carried, etc.?

On all welding we have done up to the present time we have used the oxyacetylene method. For joints to withstand pressures up to 150 lb. per sq. in., the butt weld has been used. On pressures above 150 lb., we have used the butt-welded joint, with a coupling slipped over the joint and welded at each end. (G. C. King, Consulting Engineer, Purdue University.)

Railroad

Heat-Treated Steel for Cars and Locomotives[2]

R-5 Why is not more heat-treated steel used by railroads in the construction of cars and locomotives?

The large parts used on railroad equipment are difficult to treat. The early experiences of the railroads with heat-treated materials were disappointing, and have deterred them from making further experiments. Another consideration that has prevented the adoption of heat-treated materials is the difficulty of controlling the treatment of the materials in the shops where repairs are made, as these shops may be on another railroad far removed from the owning line. (A. F. Stuebing, Chief Engineer, Bradford Corporation, New York, N. Y.)

Opportunities in the Railroad Industry[2]

R-6 Compared with other industries, what opportunity has a mechanical engineer to progress in the railroad industry?

At the present time the research committee of the Railroad Division of the A.S.M.E. is collecting data and facts pertaining to the opportunities afforded the mechanical engineer in the railroad industry. (See Progress Report, page 147, this issue.) Approximately 80 per cent of those holding the title of mechanical engineer on Class I railroads are college-trained. The average age of these men is 35 years and the average time in railroad service is 13.75 years. Quite a number of mechanical engineers transfer from railroads to railway supply companies, and vice versa. This, of course, gives the mechanical engineer another field in which railway knowledge is helpful. (M. B. Richardson, Associate Editor, *Railway Mechanical Engineer*, New York, N. Y.)

Rail Motor Cars

R-7 What railroad is the greatest user of rail motor cars and in what kind of traffic is equipment of this type used?

(*a*) The Boston and Maine is believed to be the greatest user of rail motor cars, there being a total of 24 such cars in service on that road. These cars are used in both main- and branch-line service. It is reported that there has been no difficulty in operating these cars from the standpoint of interference with through main-line traffic. They can be accelerated to speeds in relatively short distances and can maintain speeds of over 60 m.p.h. (M. B. Richardson, Associate Editor, *Railway Mechanical Engineer*, New York, N. Y.)

(*b*) The New York, New Haven & Hartford Railroad is probably the greatest user of rail motor cars, and this equipment is used principally in local suburban traffic on branch lines which will not pay the cost of operating steam trains. On some western roads these cars are used on main lines where the traffic density will not justify the expense of operating steam trains. (William Elmer, Special Engineer, Pennsylvania Railroad System, Philadelphia, Pa.)

Textile

Steam for Processing

T-7 What percentage of power is used for process steam in a cotton-spinning and weaving mill?

Although the writer has no exact figures, he would say that this amount is very small, not exceeding two or three per cent. (Thayer P. Gates, Consulting Engineer and Textile Specialist, Providence, R. I.)

Mule and Ring Spinning

T-8 Why does England use mostly mules for spinning cotton yarns, while America uses ring spinning frames?

Mule spinning produces a yarn of much more even quality and slightly stronger than yarn produced in mills using the ring spinning frame, although the mules are more expensive to operate. Many mills in this country making a point of high quality use mules instead of spinning frames, but to operate these an extra price must be obtained for quality. Apparently the reason England continues to use the mule is because of the quality of the product. (Thayer P. Gates, Consulting Engineer and Textile Specialist, Providence, R. I.)

Questions to Which Answers Are Solicited

Machine-Shop Practice

MS-6 What lubricants and coolants should be used in machining pure copper?

MS-7 How should pure copper be ground when fine precision in size is required?

MS-8 What are the present highest velocities between sliding surfaces in continuous service, and in what type of machinery? What is the nature of the material of which the surfaces are constructed? How is lubrication effected?

Fuels

F-10 What has been done to correlate the fusion temperature of coal ash with slagging in boiler furnaces? Give specific data or reference if possible.

F-11 What maximum-moisture-content coals have been successfully and continuously burned in pulverized form in unit systems? Describe operating conditions encountered, furnaces employed, and results obtained.

[2] This subject has been discussed in a previous issue.

Engineering and Industrial Standardization

Standardization of Certain Dimensions of Electric-Motor Frames

AT THE request of the National Machine Tool Builders' Association, the A.E.S.C. conducted a conference on the Standardization of Certain Dimensions of Electric-Motor Frames in New York on December 10, 1926. The conference was well attended, approximately twenty different interested organizations being represented.

The report of the Special A.E.S.C. Committee on this subject which reported in January, 1926, was first considered by the conference, after which it heard a résumé of the work done along this line by the European National Standardizing bodies.

E. F. DuBrul (general manager of the National Machine Tool Builders' Association), in opening the discussion, said that his organization had called for this standardization because the time had gone by when the motor could be attached to the machine tool anywhere and in any fashion. The modern tendency was to build the motor into the tool, and this condition made it necessary to have definite data regarding the dimensions governing the attachment of the motor and the space it occupies. At the present time there were many discrepancies in motors of the same kind, not only between different makes but even between series of the same kind of motors made by the same company on different dates. This meant that a motor ordered from a certain firm to replace a motor made previously by the same firm might not fit on the existing bedplate. The speaker pointed out that there was an increasing tendency to standardize machine-tool elements and that, for example, the standardization of T-slots was now nearing completion.

Mr. DuBrul explained that it was not the idea of the machine-tool builders to hamper the designer as to the electrical properties of the motors. In fact, the problem was very simple in his opinion. A series of standard shaft heights might be adopted, with a few (preferably, as few as possible) angles of spread for the motor legs. This was a simple problem in geometry, which would automatically lead to the adoption of certain series of standard distances between bolt holes, both at right angles and parallel to the shaft.

Col. C. A. Seoane, U.S.A., reported he had gotten in touch with the chiefs of all of the principal divisions of the War Department interested in the matter, and all proved to be in favor of undertaking the project. These chiefs were: (*a*) Chief Quartermaster General, (*b*) Chief of Engineers, (*c*) Chief of Ordnance, and (*d*) Chief Signal Officer. Colonel Seoane therefore committed the War Department on the affirmative side of the question.

Halbert P. Hill (American Society of Refrigerating Engineers) said he could appreciate both sides of the question, having been a manufacturer of electric motors and now representing the A.S.R.E, whose members were users of electric motors. He said that his experience as a manufacturer had shown that machine-tool builders would often ask for motors of very diverse requirements and expect the manufacturer to live up to these. He could see that standardization would be valuable, but it did not seem possible to him to cover a field as broad as the machine-tool builders had in mind. He thought, therefore, that a universal standard could not be set up, but that it might be possible to establish certain classes of applications of motors, for each of which a maximum space might be established so that any motor of a certain class might be applied.

J. L. Minick (Association of Railway Electrical Engineers) said that the railroads were large users of electric motors, his own company having more than 25,000 in use, and the members of the association he represented very likely between 300,000 and 500,000. Standardization in this field appealed very strongly to them and the railroads themselves had already found it useful to adopt certain standards about six or seven years ago when, as it had happened, one railroad used 67 different makes, and repair parts had to be carried for all of them. In one particular plant there were 400 different sizes and shapes of motors. As to generating power for providing electric light on trains, this equipment was being supplied by 12 different makers but the dimensions had been boiled down to one set for each given size. The speaker was therefore in favor of starting the project.

J. M. Hipple (National Electric Manufacturers' Association and also representing the American Electric Railway Association), said that the electrical manufacturers were not opposed to a certain degree of standardization in the field under consideration, but there were difficulties arising from the design of motors which made it impossible to lay down fixed dimensions for their frames. Motor design was constantly changing and improving, and the speaker cited as an example that in the course of nineteen years the weight of a 5-hp. motor had been reduced from 975 to 175 lb. Therefore, he was of the opinion that laying down fixed dimensions for the frames would hamper progress, as it was not possible to predict just what the further development of motor design would be. One of the difficulties was also the difference in the electrical properties of the motors (single-phase, polyphase, and d.c.), as it was obvious that a d.c. and a polyphase motor of the same horsepower rating had very different dimensions. The manufacturers were doubtless in favor of standardization in general, which worked out also to their own advantage, and on this particular project they were in favor of taking certain steps which, however, should be limited to the establishment of a series of preferred numbers to be used in machine design in a general way. In other words, such preferred numbers should not only apply to electric-motor frames, but also to pumps, machine-tools, and other driven devices so as to foster uniformity. However, going beyond this limit would mean the blocking of sound progress.

It was then moved and carried that sectional committee be organized under procedure of the A.E.S.C. to take up the work.

The conference then voted to recommend the following items which appeared on the agenda for the conference as the scope of the project:

a A series of standard dimensions for the distance from the base to center of shaft (shaft height);

b A series of standard distances between bolt holes, at right angles to the shaft;

c A series of standard distances between bolt holes, parallel to shaft;

d Certain definite combinations of a shaft height with any or both of the distances between bolt holes as mentioned under (*b*) and (*c*); with the addition of the following item:

e Maximum diameter and length of the motor.

Standardization of Heating-Boiler Ratings

FOR some time the matter of rating low-pressure heating boilers has been in a chaotic condition and has been unsatisfactory to engineers, architects, manufacturers, and contractors throughout the country. The situation was noted by the United States Bureau of Mines and called to the attention of the American Society of Heating and Ventilating Engineers, as a most disturbing condition in the industry. The Bureau suggested the appointment of a committee to study the situation from all angles, and urged the society strongly to take up this matter in an effort to provide a satisfactory solution of the rating question, particularly as the repeated efforts of manufacturers and others had failed because of competitive conditions and trade jealousies.

H. P. Gant, Chairman of the A.S.H.V.E. Committee on Research, responded to this appeal and appointed a Technical Advisory Committee with the following personnel: Alfred S. Kellogg, Consulting Engineer, Boston, *Chairman;* Percy Nicholls, Fuel Engineer, U. S. Bureau of Mines, Pittsburgh; L. E. Seeley, Sheffield Scientific School, Yale University, New Haven, Conn., and F. C. Houghten, Director of the A.S.H.V.E. Research Laboratory, Pittsburgh.

No member of this Committee is in any way connected with the trade, and each has accepted the difficult responsibility of finding a solution to the boiler-rating problem with the thought of establishing a plan that would be to the best interests of the public at large. Several meetings have been held and on December 8 and 9, 1926, all-day conferences were held and a working plan adopted. The outline of this plan is now being sent out in a letter from the Committee to the boiler manufacturers of the country in order to learn whether the trade really desires to have this unsatisfactory boiler-rating condition cleared up and a uniform standard of rating established, or whether the manufacturers prefer the present chaotic conditions to continue.

From the results of this survey the Committee drafted a report which was presented at the A.S.H.V.E. annual meeting in St. Louis, January 26 to 28.

Standard Size for Garden Hose

GARDEN hose is made in several sizes, ranging from $^1/_2$ to 1 in., inside diameter. In recent years there has been a strong tendency on the part of manufacturers to encourage the use of $^5/_8$-in. hose in place of the $^1/_2$- and $^3/_4$-in. sizes. This standardization of size seems desirable for several reasons. It would tend to reduce the cost of manufacture by eliminating two unnecessary sizes, and at the same time it would reduce the amount of stock to be carried by dealers.

That the $^5/_8$-in. size is large enough for ordinary purposes has been demonstrated by tests recently made at the Bureau of Standards to determine the discharge capacities of $^1/_2$-, $^5/_8$-, and $^3/_4$-in. hose under different pressures. It was found that the discharge capacity of $^5/_8$-in. hose is only slightly less than that of $^3/_4$-in. hose, and that it is considerably greater than that of $^1/_2$-in. hose. The detailed results of these tests, together with general information relative to the selection, use and care of garden hose, will appear in a forthcoming circular of the Bureau.

Correspondence

CONTRIBUTIONS to the Correspondence Department of Mechanical Engineering are solicited. Contributions particularly welcomed are discussions of papers published in this journal, brief articles of current interest to mechanical engineers, or comments from members of The American Society of Mechanical Engineers on activities or policies of the Society in Research and Standardization.

Landmarks in the History of Prime Movers

TO THE EDITOR:

In the December, 1926, issue of MECHANICAL ENGINEERING, in the article entitled Landmarks in the History of Prime Movers, there are two errors in the captions attached to the illustrations. The first of these fixed the date of the invention of Hero's aeolipile at 50 A.D. According to all histories of the steam engine which I have read, the aeolipile was devised in the second century before Christ. In the article on the steam engine in the Encyclopedia Britannica it is stated that Hero's Pneumatica describing this and other types of heat engines was published about 130 B.C.

In another illustration, that of the model of the Newcomen engine repaired by James Watt, reference is made to the laboratory of the University of Edinburgh. As a matter of fact, it was in the laboratory of the University of Glasgow where Watt worked for a number of years as a mechanician, and where his first invention of the separate condenser and other devices were made.

C. R. RICHARDS.[1]

Bethlehem, Pa.

[Dr. Richards is certainly correct when he locates the model Newcomen engine in the laboratory of the University of Glasgow at the time when James Watt repaired it. Andrew Carnegie in his book, James Watt (Doubleday, Page & Company, N. Y., 1905), tells what a great service this famous university rendered to the young inventor, and thereby to the world in general, at that period. Because Watt had not served a seven years' apprenticeship, the Guild of Hammermen of Glasgow barred him out from practicing as a mathematical-instrument maker in that city. In this emergency the professors of the University of Glasgow, who by the charter of 1451 had absolute authority within the area of the buildings, resolved to give Watt shelter there. They installed him as the instrument maker in their laboratory, and Mr. Carnegie says it was "the best day's work they ever did."

In regard to the date of the Aeolipile of Hero of Alexandria, Dr. Richards bases his correction upon what should be good authority. There is a difference of opinion on this date, however, and the Smithsonian Institution, from which the cut and the caption were obtained, places it around 50 A.D. Among other authorities for this the Catalogue of the Mechanical Engineering Collection in the Science Museum, South Kensington (1919), may be quoted. The chapter on Stationary Steam Engines in this book opens as follows: "The earliest known record of the employment of steam as a motive agent is that of Hero of Alexandria, a philosophical writer who flourished, it is now believed, about 50 A.D."—EDITOR.]

[1] President, Lehigh University. Mem. A.S.M.E.

A.S.M.E. Boiler Code Committee Work

THE Boiler Code Committee meets monthly for the purpose of considering communications relative to the Boiler Code. Any one desiring information as to the application of the Code is requested to communicate with the Secretary of the Committee, Mr. C. W. Obert, 29 West 39th St., New York, N. Y.

The procedure of the Committee in handling the cases is as follows: All inquiries must be in written form before they are accepted for consideration. Copies are sent by the Secretary of the Committee to all of the members of the Committee. The interpretation, in the form of a reply, is then prepared by the Committee and passed upon at a regular meeting of the Committee. This interpretation is later submitted to the Council of the Society for approval, after which it is issued to the inquirer and simultaneously published in MECHANICAL ENGINEERING.

Below are given interpretations of the Committee in Cases Nos. 432, 453, 465, 536 and 537, as formulated at the meeting of December 3, 1926, all having been approved by the Council. In accordance with established practice, names of inquirers have been omitted.

CASES ANNULLED

By resolution of the Boiler Code Committee at its meeting of December 3, 1926, the following Cases and a Communication have been ordered withdrawn and cancelled:

CASE NO. 432 (Annulled)

CASE NO. 453 (Annulled)

CASE NO. 465 (Annulled)

CASE NO. 536

Inquiry: Is it permissible, under the requirements of the Code for Unfired Pressure Vessels, to electrically weld the calking edges of seams of tanks in place of the customary mechanical calking specified in Par. U-52?

Reply: Par. U-52 is mandatory in its requirement for mechanical calking of seams of riveted tanks, and fusion welding as a substitute therefor is obviously not permissible.

CASE NO. 537

Inquiry: Is it the intent of Par. P-322 that the requirement for taking the water connection for a water column at a point not less than 6 in. below the center line of the shell, shall apply to all types of horizontal-return tubular boilers, including such boilers of portable construction with internal cylindrical furnaces, or does it apply only to the externally fired brick-set h.r.t. boilers?

Reply: The type of boiler referred to in the inquiry is of the Scotch dry-back type to which the requirement of Par. P-322 does not apply.

MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

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Contributions of interest to the profession are solicited. Communications should be addressed to the Editor.

BY-LAW: The Society shall not be responsible for statements or opinions advanced in papers or.....printed in its publications (B2, Par. 3).

Progress in Steam Research

THIS issue contains the Annual Progress Report on the Steam Table Research being conducted under the auspices of the A.S.M.E. It also contains in the Survey of Engineering Progress an abstract of an address before the Royal Society by Professor Callendar telling the results of his interesting researches in the same field.

The problem of steam properties at high temperatures is occupying an important place in the minds of physicists and engineers throughout the world. From the work of the many investigators now busied with the subject must come valuable additions to present knowledge. It is the hope of all who use such data that the results obtained in the various researches may be coördinated so that the final data will carry the greatest possible authority.

Mathematics and Common Sense

SINCE the appearance of our editorial entitled Mathematics Is a Language, in which was quoted John Perry's designation of mathematics as the tool of the engineer, we have had the pleasure of reading an address by Prof. Gilbert Ames Bliss before the A.A.A.S. on the Contributions of Mathematics to Industry.

Professor Bliss presents a very human apology for pure mathematics, and interprets the ideals of the pure mathematician whose work must lie in the ever-widening frontiers of his subject. Like the discoveries of the chemist and the physicist, the researches of the mathematician may be destined to become the commonplaces of tomorrow, the tools which the scientist and the engineer may learn to use as they have learned to apply the researches of yesterday's mathematicians in the problem of today. Witness, for instance, the rather common use of Fourier's series and the increasing dependence on the mathematics of relativity.

But Professor Bliss sees an even wider field for mathematics when he says that "mathematics may sometimes be a guide and not merely a tool in engineering research." To illustrate his thought he mentions the application of mathematics to the calculation of electrical networks in telephony; and this brings to mind the well-known stories of the finding of celestial bodies by mathematical computations. The fascinating possibilities for this application of mathematics seem almost limitless. Here are the chart and compass by means of which the modern navigator of engineering seas directs his voyage to a desired haven instead of sailing blindly over unknown seas in search of a terra incognita.

It is natural that Professor Bliss should be impatient with practicing engineers who show reluctance in admitting that mathematics plays an essential role in engineering problems, and that he should not be in agreement with the mistrust of mathematics expressed by Professor Swain in the last chapter of his text on the Strength of Materials. To Professor Swain's adjuration to use common sense in avoiding mathematics where mathematics is inapplicable, he adds the further principle that "common sense should also be scrupulously avoided in places where common sense does not apply. No amount of common sense, unaided," he writes, "can predict the motions of the heavenly bodies, or compute a range table."

And finally, Professor Bliss rests his case in expressing three hopes which appear reasonable enough: "That the calculus may be presented earlier and more clearly in our college curricula, and that it may become a familiarly convenient tool and friend to the practicing mathematician instead of a stumbling block and a barrier. . . ; that avenues of communication between the industrial and mathematical world may be opened; and that we may have in America a school of applied mathematics . . . which in numbers as well as personnel shall be comparable with the dignity of our representatives in other sciences."

Teaching Physics in Engineering Units

ENGINEERS in general and teachers of engineering in particular will be interested in the announcement which comes from the department of physics at New York University that it will use engineering units in teaching physics to students in the College of Engineering.

Many engineers have felt that there is needless confusion in the mind of the engineering student because he is required to use one set of units while studying physics, and another set while studying mechanics or thermodynamics. After having thought in kilograms and calories while studying physics, the student must forget these terms in order to think clearly in pounds and B.t.u., and the fundamental constants which he has learned in one system must be converted into different constants for use in the computations of his engineering courses.

While the confusion which exists because of the two systems of units, one used by scientists and the other by engineers, may be a strong argument for the adoption of a single and common system, the experiences of those who have labored to bring about a reform have always been disappointing, and the student has been without relief. There is usually enough to puzzle young minds in the principles and computations of engineering subjects without the added complication of two sets of units, one of which applies in engineering and the other in physics courses.

The Industrial Use of Fundamental Research

WHEN the relation between research in pure science and industry is considered, two viewpoints are possible—one that of the researcher in pure science, and the other of industry. As Dr. Willis R. Whitney presents the situation from the viewpoint of the former, the man who is pursuing research in pure science is primarily impelled by the divine curiosity to know the reason why. This may lead the scientist into an investigation of the limitless interplanetary spaces measured in hundreds of thousands of light years, or of the motions of electrons where the dimensions involved are subinfinitesimal. In doing so the scientist is not at all concerned with what might be crudely termed the dollars-and-cents value of any results he may obtain. As Dr. Whitney points out correctly, the moment research is undertaken with a certain definite practical aim it ceases to be research in pure science, even though it deals with problems of pure science.

The attitude of industry and its spokesman in this connection, the engineer, is, however, entirely different. Industry has numberless problems to solve in the way of producing new materials and new results, in the way of improving the quality of old materials or reducing their cost of production. The industrial engineer is therefore going about the world with his eyes open, keenly on the

lookout for anything that may help him solve his innumerable problems. He is more and more learning that he can make the most profitable use of discoveries in pure science. The opinion once quite generally held by so-called practical man that the work of the professors was good only to eat up the taxpayers' money and to tickle the vanity of the former, is very rapidly disappearing in the face of big industrial developments entirely based on data obtained by research in pure science, and by men who neither realized what they were doing for industry nor would have cared about it if they had.

The electromagnetic theory of Maxwell was on the face of it one of the driest pieces of mathematico-physical reasoning, understood at first by even fewer than the sacred twelve who are today supposed to be capable of reading understandingly the works of Einstein. Later Professor Hertz carried out some experiments on reflection and refraction of electromagnetic waves by mirrors and prisms made of pitch, an interesting but apparently "impractical" piece of work, and then came the practical engineers, men like Marconi, Fleming, and others, who took these bits of theoretical knowledge, devised the apparatus that was needed to give them life, and created the vastly important radio telegraph and telephone industry which is reshaping today our means of communication.

The important thing to realize is that modern engineering, taking this term in its broad sense, is today so extensive in its applications that there is scarcely a scientific discovery that will not rapidly find application. Work on catalysis, adsorption, the theory of films, suspensions either in gases or liquids, the structure of atoms—all things which would have been considered abstruse theory twenty years ago—are today finding extensive application in industry. As a matter of fact, the engineering profession can now afford to support research in pure science without placing any restrictions on the researcher, because in a large proportion of cases it will be able to use the results obtained in one way or another. Knowledge of the facts of the universe has a definite and immediate value, no matter to what realm of the universe it may belong. One man started to search for the why's and wherefore's of the reflection of sound, and ended by devising a method for measuring the depth of the ocean. Another built a highly sensitive instrument for measuring the gravitation of the earth, only to have it converted into a means of discovering hidden oil deposits; and a third man, starting by studying bacterial phenomena, was led to the development of a process for making paper out of reeds. In the olden days all roads were said to lead to Rome. Today in science, no matter by which road or in which direction a man proceeds, he is bound to encounter something useful for the betterment of humanity and the progress of industry.

The Elimination of Harmful Noises

IT SEEMS inevitable that advances in our material civilization are accompanied by an increase in noise. The not unmelodious song of the laborer of twenty years ago has given place to the prodigious snorting of the steam shovel; the din of pneumatic riveters has drowned out the scrape of the mason's trowel; methods of transportation have made greater advances in noise than in rapidity; and recently "talking movies" and radio loud speakers have added to the general roar of modern life. Even the police are no longer content with rubber heels and bicycles, but must go about on barking motorcycles; and modern firemen must rush shrieking through empty streets in the dead of night as though they expected to arouse to their assistance the terrified hundreds of sleepers they awaken.

From time to time efforts have been made to reduce or suppress noise. Districts surrounding hospitals have been designated "quiet zones;" shipping in New York Harbor has been restrained from the unnecessary use of steam whistles; muffler cut-outs have been banned (although trucks with inadequate mufflers are still tolerated); and the sounding of automobile horns by motorists caught in traffic jams is being broken up by the police. But these and other attempts, successful in some instances and for short periods of time, do not get at the heart of the problem of the elimination of noise.

A report of the Committee on the Elimination of Harmful Noises of the American Society of Safety Engineers concludes as follows: "The perplexing part of this whole problem is that with all the general opinions of medical experts and others assuring us that noise is detrimental to the nervous system, there has been no research definitely to prove or disprove it. Therefore, the further work of the committee should be directed to the seeking of definite information along those lines. If such research can definitely show the destructive effects of noise and confirm medical and judicial opinions, definite recommendations for the suppression of those noises that are shown to be harmful can then be made and enforced."

This appears to be the crux of the whole matter. Until we can count the cost in dollars and cents, in nervous energy, and in public health, no headway can be made against noise in general. Other economic factors will outweigh the complaints of an angry neighbor, who will be told to accustom himself to the noise of a city or seek the solitude of a rural retreat. But once facts have been established to prove that not only the angry neighbor but the one who suffers without complaint is being robbed of health, or sanity, or both, then noise elimination becomes an economic necessity, and means will be found to suppress it. The engineer is doubly interested in the problem of noise elimination because many of the objectionable noises are due to conditions in industry and transportation which he has created, and because ultimately the public will look to him for relief.

A decade ago, machinery left the manufacturer with exposed gears and set screws. The workman *had* to be careful. Today it has been found that there is greater economy in paying a little more for a protected machine and a little less for accidents. Is it too much to hope that industrialists will take a corresponding view of noise elimination? If "safety first," why not "sanity first?"

France Builds Airplanes by Ford Methods

INFORMATION has been received from France that the Breguet Airplane Company has installed a conveyor system for assembling airplanes that is somewhat similar in principle to the famous Ford conveyor assembly. This piece of news is highly significant. The Breguet plane is extensively used by the French military authorities as well as by commercial companies. It is with Breguet machines that some of the long-distance records of last summer in flights from Paris to various points in southern and northern Asia and central Africa were made. It is obvious that assembling airplanes on a conveyor system would have been done only to speed up production, and the fact that the French aircraft industry has reached a point where at least one company has had to resort to such means to get out the desired number of planes, is a very clear indication of the state of development which the industry has reached. Obviously a conveyor would not be installed for an output of one or two machines a day. The production must not only have reached a substantial volume to justify such an installation, which would otherwise look ridiculous, but it must have also been sufficiently standardized, as it is only with a small number of types that a conveyor assembly would pay.

The cost of labor in France, particularly in view of the present depreciated currency, is so low that as a rule it does not pay to install expensive machinery in order to reduce the consumption of labor. It is only in countries of high labor costs like the United States that expensive labor can be profitably replaced by machinery, the installation of which may be costly but the operation of which is cheap. Under the conditions prevailing in France there would obviously be no incentive to install a conveyor system to save labor costs, and the only aim of such a method of assembly must be the desire of increasing the output. Obviously, it would not be worth while to spend money to speed up production if the market for airplanes did not justify it, the French being notoriously very close calculators of costs and profits. To those who still doubt the value of the airplane, be it in the military or civil establishments of nations, the conveyor assembly at the Breguet Works would seem to give a plain indication that at least in France this type of aircraft has decidedly come to stay. No conveyor systems for the assembly of airplanes have as yet been installed in the country of birth of the airplane, however.

Opportunities of the Mechanical Engineer—The Railroad and Railroad-Supply Industries

MOST engineers and students of engineering are at some time confronted by the question as to the field of activity in which they may employ the knowledge they possess or they hope to possess upon graduation most profitably. Numerous articles have appeared in the trade and technical press, and letters and editorial comments without number have appeared in print in which advice of both good and questionable character has been offered. Little more than a casual perusal of these contributions is necessary to convince one that many of the contributors have well-defined opinions that certain industries want college men but are unwilling to go after them or to pay salaries commensurate with the education and training that the men they desire have received. Another impression quickly formed is that few college men are willing to spend the necessary time in subordinate positions to acquire the experience expected of them. Opinions to the contrary also may be found without much effort, so the resulting picture, to the eyes of the young engineer, is of a decidedly confusing nature.

Unless steps are taken by some neutral agency to prevent further magnification of fancied conditions, it does not require a great deal of imagination to visualize the chaos that is sure to result. Mechanical engineers most naturally turn to the A.S.M.E. for counsel in times of uncertainty, and it is but natural to suppose that some assistance is expected in the present situation. Anticipating this, the Society has already taken steps toward relief through an effort to establish a sounder basis for the formation of opinions. The railroad and railroad-supply industries having received more adverse comment than was believed justified, steps were taken to study conditions in these fields first. Accordingly, a Sub-Committee on Professional Service was appointed by the Railroad Division to undertake an investigation and report to the Society. The first progress report appears on page 147 of this issue of MECHANICAL ENGINEERING under the title: Opportunities Afforded the Mechanical Engineer in the Railroad and Railroad-Supply Industries.

In the preparation of this document and in its subsequent investigations, a report of which will be presented during the next Annual Meeting, the Sub-Committee has diligently sought basic facts. Too often rumors and opinions based on unfortunate experiences are accepted as facts, and continued circulation does not lessen their apparent magnitude. The work of the Sub-Committee has been divided into two parts: namely, collecting and assembling facts by library search, and approaching railroad and railroad-supply companies directly.

Questionnaires to these companies are so framed that through the resulting information the careers of officials may be studied and the steps between the humble beginner and the executive enumerated; methods by which the college man may gain promotion in railroad work are being disclosed; information as to the departments making up a great railroad organization is being assembled. Facts relative to the relationship between the railroad and railroad-supply industries also are being sought.

Further valuable information is contained in a comparison of these two industries with thirteen general groups of industries employing mechanical engineers. Tables showing the number of employees holding positions where mechanical-engineering training would be of service on Class I railroads will help in the choosing of a method of attack. A tabulation of the average ages of twenty-five officers, the time required to reach certain positions and time gained by college graduates may be the means of bolstering up the courage of one about to allow success to evade him through hesitancy born of improper age valuation.

It must be remembered, however, that the function of the Sub-Committee is to point the way. It cannot supply the will to do things, nor can it make the preparations and assume the responsibilities required of the individual who would enter either of these fields and benefit thereby. The lover of mountain climbing may have the guidance of one who is familiar with the rough passages and points of danger and who can point these out accurately, as well as indicate where the most beautiful views may be found in the ascent; but the will to reach the summit is entirely within the climber. Furthermore, the speed of the ascent, once the determination to make the climb has been established, depends upon the ability of the climber to recognize the magnitude of the obstacles confronting him, and his ability to either circumvent them or remove them entirely. So it is with the progress report and the final report promised. Data as to conditions found by the Sub-Committee will be available for the engineer's convenience and edification; it is his task to determine whether or not he is willing to face the obstacles and fight his way to the goal, or whether it is better to step into another field and pit his strength against the obstacles therein.

For the benefit of the engineer who would enter other fields, similar activity on the part of other Divisions of the Society will go far toward reducing the confusion and haze associated with records of progress and opportunities for development.

Engineers Are Not Narrow Technicians

ENGINEERS have generally been too busy with their professional work and too unassuming to have either the time or the inclination to seek publicity for themselves and for their profession. The engineering profession probably has called for more persistent and concentrated brain work on the part of those practicing it per dollar earned than any other. This fact, coupled with the fact that the work is such as to tend to carry itself over in the mind of the worker into what for other men are hours of leisure and recreation, has conspired to label engineers in general as men with single-track minds—rather unsociable men, perhaps.

If as much publicity had been given to the essential breadth of the field of mechanical engineering, and to the remarkable number of versatile and personable characters who have followed it, the popular conception of this profession and of its followers would today be diametrically opposite to what it is.

Several years ago Rear Admiral Bradley A. Fiske, himself an able inventor and engineer, wrote a book entitled Invention—the Master Key to Progress. This presents an outline of the history of invention and engineering from the earliest times, and gives a glimpse into the future. In this book it is again and again brought out that it is the privilege of inventors and engineers, as it is of artists, sculptors, poets, novelists, composers, etc., to be able to seize from a mysterious source abstract things called ideas, which they crystallize into tangible things for the betterment of mankind. The only differences between the engineers and the other "creative artists" are in the materials in which they work and the uses to which their creations are put.

This basic similarity between the "mechanic arts" and the "fine arts" may explain why so many engineers have been artists in their spare time, and also why on the other hand so many artists have at the same time been engineers. The term "artists" is not limited here to those who express themselves by painting pictures, but covers also those who express themselves ably in many other ways, such as in the appreciation of music or even in the study of astronomy.

One cannot go far in the study of the history of engineering without discovering this—no further than the consideration of Leonardo da Vinci, who is the classic example. From Leonardo da Vinci to James Nasmyth there have been many engineer-artists and many artist-engineers. There have been many engineer-artists in The American Society of Mechanical Engineers: they were among its founders and they have held high places in the engineering profession. Many such men are in the profession and active in the Society today. Representative engineers are broad-minded men—interesting men—sociable men—and the world is just beginning to find it out—to the benefit of the world and to the benefit of the profession.

A Correction

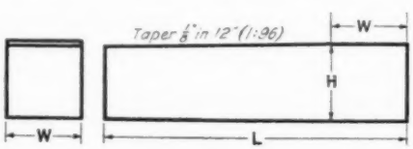
IN THE foreword to the Joint Research Committee on Boiler Feedwater Studies on p. 1361 of the Mid-November, 1926, issue of MECHANICAL ENGINEERING, the American Boiler Manufacturers' Association should have been included in the list of sponsors given for that Committee.

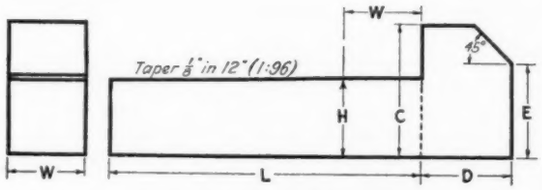
Tentative Standards for Gib-Head and Plain Taper Keys

IN OCTOBER, 1918, the American Engineering Standards Committee authorized the organization of a Sectional Committee on the Standardization of Shafting. This work is sponsored by The American Society of Mechanical Engineers. The Sectional Committee consists of fourteen (14) representatives of five (5) national organizations, and is composed of manufacturers, consumers, and general interests.

Sub-Committee No. 4 of the Sectional Committee was appointed to study and complete a standard on Gib-Head and Plain Taper Keys.

The results of the Sub-Committee's work are embodied in the accompanying tables. In arriving at its results the Sub-Committee has studied all the available information regarding present practice and has altered a few dimensions when such action seemed advisable in order to secure a consistent series of gib heads. The recommended lengths of the stock taper keys are, in some cases, a departure from present practice, but are based on a uniform rule by which the minimum stock length is taken as four times the key width, and the maximum stock length as sixteen times the key width, with increments of two times the key width. The tolerances for key widths are kept the same as for the square and flat stock keys, and the tolerances for thickness or height of key are the same as for square or flat stock keys but opposite in direction, being plus instead of minus. The height of the taper key is to be measured a distance from the large end or from the face of the gib





Dimensions and Tolerances

Diameters of Shafts (Inclusive)	Square Type: Key: Maximum Width W	Square Type: Key: Minimum Height Large End[1] H	Square Type: Gib Head: Height C	Square Type: Gib Head: Length D	Square Type: Gib Head: Height Edge of Chamfer E	Flat Type: Key: Maximum Width W	Flat Type: Key: Minimum Height Large End[1] H	Flat Type: Gib Head: Height C	Flat Type: Gib Head: Length D	Flat Type: Gib Head: Height Edge of Chamfer E	Tolerances on Keys: Width (Minus)	Tolerances on Keys: Height (Plus)
½ – 9/16	⅛	⅛	¼	7/32	5/32	⅛	3/32	3/16	⅛	⅛	0.0020	0.0020
5/8 – ⅞	3/16	3/16	5/16	9/32	7/32	3/16	⅛	¼	3/16	5/32	0.0020	0.0020
15/16–1 ¼	¼	¼	7/16	11/32	11/32	¼	3/16	5/16	¼	3/16	0.0020	0.0020
1 5/16 –1 ¾	⅜	⅜	11/16	15/32	15/32	⅜	¼	7/16	⅜	5/16	0.0020	0.0020
1 13/16–2 ¼	½	½	⅞	19/32	⅜	½	⅜	5/8	½	7/16	0.0025	0.0025
2 5/16 –2 ¾	5/8	5/8	1 1/16	23/32	¾	5/8	7/16	¾	5/8	½	0.0025	0.0025
2 7/8 –3 ¼	¾	¾	1 ¼	⅞	⅞	¾	½	7/8	¾	5/8	0.0025	0.0025
3 3/8 –3 ¾	⅞	⅞	1 ½	1	1	⅞	5/8	1 1/16	⅞	¾	0.0030	0.0030
3 7/8 –4 ½	1	1	1 ¾	1 3/16	1 3/16	1	¾	1 ¼	1	13/16	0.0030	0.0030
4 ¾ –5 ½	1 ¼	1 ¼	2	1 7/16	1 7/16	1 ¼	⅞	1 ½	1 ¼	1	0.0030	0.0030
5 ¾ –6	1 ½	1 ½	2 ½	1 ¾	1 ¾	1 ½	1	1 ¾	1 ½	1 ¼	0.0030	0.0030

Diameters of Shafts (Inclusive)	Stock Length of Key[2] (L)						
½ – 9/16	½	¾	1	1 ¼	1 ½	1 ¾	2
5/8 – ⅞	¾	1 ⅛	1 ½	1 ⅞	2 ¼	2 ⅝	3
15/16–1 ¼	1	1 ½	2	2 ½	3	3 ½	4
1 5/16 –1 ¾	1 ½	2 ¼	3	3 ¾	4 ½	5 ¼	6
1 13/16–2 ¼	2	3	4	5	6	7	8
2 5/16 –2 ¾	2 ½	3 ¾	5	6 ¼	7 ½	8 ¾	10
2 7/8 –3 ¼	3	4 ½	6	7 ½	9	10 ½	12
3 3/8 –3 ¾	3 ½	5 ¼	7	8 ¾	10 ½	12 ¼	14
3 7/8 –4 ½	4	6	8	10	12	14	16
4 ¾ –5 ½	5	7 ½	10	12 ½	15	17 ½	20
5 ¾ –6	6	9	12	15	18	21	24

All dimensions in inches.
[1] NOTE 1.—The thickness of the key is measured at the distance "W" from the large end.
[2] NOTE 2.—The minimum stock length of keys is equal to four times the key width, and the maximum stock length of keys is equal to sixteen times the key width. The increments of increase of length are equal to two times the width.

Dimensions and Tolerances

Diameters of Shafts (Inclusive)	Square Type: Key: Maximum Width W	Square Type: Key: Minimum Height Large End[1] H	Flat Type: Key: Maximum Width W	Flat Type: Key: Minimum Height Large End[1] H	Tolerances: Width (Minus)	Tolerances: Height (Plus)
½ – 9/16	⅛	⅛	⅛	3/32	0.0020	0.0020
5/8 – ⅞	3/16	3/16	3/16	⅛	0.0020	0.0020
15/16–1 ¼	¼	¼	¼	3/16	0.0020	0.0020
1 5/16 –1 ¾	⅜	⅜	⅜	¼	0.0020	0.0020
1 13/16–2 ¼	½	½	½	⅜	0.0025	0.0025
2 5/16 –2 ¾	5/8	5/8	5/8	7/16	0.0025	0.0025
2 7/8 –3 ¼	¾	¾	¾	½	0.0025	0.0025
3 3/8 –3 ¾	⅞	⅞	⅞	5/8	0.0030	0.0030
3 7/8 –4 ½	1	1	1	¾	0.0030	0.0030
4 ¾ –5 ½	1 ¼	1 ¼	1 ¼	⅞	0.0030	0.0030
5 ¾ –6	1 ½	1 ½	1 ½	1	0.0030	0.0030

Diameters of Shafts (Inclusive)	Stock Length of Key[2] (L)						
½ – 9/16	½	¾	1	1 ¼	1 ½	1 ¾	2
5/8 – ⅞	¾	1 ⅛	1 ½	1 ⅞	2 ¼	2 ⅝	3
15/16–1 ¼	1	1 ½	2	2 ½	3	3 ½	4
1 5/16 –1 ¾	1 ½	2 ¼	3	3 ¾	4 ½	5 ¼	6
1 13/16–2 ¼	2	3	4	5	6	7	8
2 5/16 –2 ¾	2 ½	3 ¾	5	6 ¼	7 ½	8 ¾	10
2 7/8 –3 ¼	3	4 ½	6	7 ½	9	10 ½	12
3 3/8 –3 ¾	3 ½	5 ¼	7	8 ¾	10 ½	12 ¼	14
3 7/8 –4 ½	4	6	8	10	12	14	16
4 ¾ –5 ½	5	7 ½	10	12 ½	15	17 ½	20
5 ¾ –6	6	9	12	15	18	21	24

All dimensions in inches.
[1] NOTE 1:—The thickness of the key is measured at the distance "W" from the large end.
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equal to the key width. This, together with the plus tolerance, provides a height to allow for driving the taper key into place.

Now that the Sectional Committee has approved these standards, they are before the Sponsor for approval and transmission to the American Engineering Standards Committee. Copies of these standards in page-proof form are now available to those especially interested and may be procured by addressing C. B. LePage, A.S.M.E., 29 West 39th Street, New York, N. Y.

The machinery mortality rate in the United States is high. In accordance with the axiom that the faster one goes ahead the more one leaves behind, the American manufacturer is in the habit of scrapping old machines and factories to make way for new and better ones.

This brings him into controversy with the income-tax collector. Every train arriving at Washington deposits comptrollers, corporation treasurers, attorneys and certified accountants with brief cases bulging with papers relating to income-tax disputes, a large proportion of which, according to the Department of Manufacture of the Chamber of Commerce of the United States, relate to depreciation of machinery and other properties used in production.

To determine the average length of life of machinery in different industries the Department of Manufacture has embarked upon a study of this phase of depreciation, coöperating with trade associations. The aim is the establishment of mortality standards for machinery for the guidance of the income tax collectors as well as industry—to determine, in other words, the average pace of progress and how fast machines succumb to the ravages of old age and the competitive onslaught of newer and more effective machines.—*New York Commercial*, December 31, 1926.

Problems of Educational Policy and Practice in Engineering Schools

THE BASIC process of engineering education as pointed out in the Preliminary Report of the Board of Investigation and Coördination of the Society for the Promotion of Engineering Education, November, 1926, should be an undergraduate curriculum of coherent and integral structure, directed to the grounding of the student in the principles and methods of engineering and also in those elements of liberal culture which serve to fit the engineer for a worthy place in human society and to enrich his personal life.

A college training which prepares for entry to productive life at a normal age of from twenty-two to twenty-three is as much as can be justified for the majority of engineering students. Limitations of the formal scholastic program, for the time being, concludes the Board, must be offset by more extended provision for further training after graduation.

Information in possession of the Board indicates that the normal length of the undergraduate curriculum should remain four academic years, and it is recommended that it include not in excess of 144 credit units, exclusive of required physical and military training and required summer courses. Six distinct subjects of instruction to be carried simultaneously are suggested as a maximum limit consistent with efficiency of effort.

Social and Economic Content of Curriculum. The ability of the engineer to extend his influence in industrial organizations and in public life, to claim his due share of leadership and to discharge more adequately his function in society at large, now appears to hinge primarily on his attainment of greater competency and greater recognition of the economic and social side of his work. These considerations lend a high importance to the social sciences as an essential part of an adequate engineering education, and the Board concludes that considerations of social and financial economy deserve a large place in all distinctly engineering subjects.

Admissions. Admission by certificate should be accompanied by more selective methods, involving any or all of the following:

1 Scholastic records in mathematics, sciences, and English above mere passing grades.

2 A general scholastic standing in a designated fraction of the class

3 Special recommendation of fitness by the high-school principal

4 A test of general intelligence

5 Training and aptitude tests in specified subjects

6 Physical and health examinations to discover remedial defects and eliminate those hopelessly handicapped.

Non-Graduate Students. The present proportion of non-graduating students in engineering colleges is plainly excessive and indicates a negative handling of a group of important problems. Some of the measures calculated to aid in the solution of this problem include: A selective plan of admission; encouragement and assistance to the establishment and development of institutions offering briefer and more intensive programs of technical education; elimination of negligent students during the freshman year; permission to transfer to non-engineering courses after failure to show aptitude; where provision must be made for large numbers of non-graduates, as much as feasible of the more concrete and practical content of the curriculum should be placed in the first two years; competent personnel supervision to deal constructively with cases of impending failure.

Exceptionally Gifted Students. The present scheme of closely supervised work in connection with an orderly plan of class and laboratory exercises is well adapted to the needs of the majority of engineering students. Some more distinctive plan, however, should be made for the needs of exceptionally able and self-reliant students who fail to receive the maximum stimulation of their initiative and resourcefulness in closely regimented work.

Teaching Personnel. Each engineering college should have a carefully worked-out policy and program for the enlistment and upbuilding of its teaching staff. The attention of promising young men should be directed to a teaching career; prospects for teaching appointments should be guided into suitable programs of advanced study in strong graduate schools, or into suitable programs of engineering experience; young teachers should be assisted to make and build up professional contacts and non-teaching activities, through association with practical engineers, industrial organizations, and professional societies; research, preferably with the direct coöperation of industries, professional societies and trade associations, should be promoted as a means of developing young men for the teaching staffs. More attention should be given to compensation, and engineering teachers should be allowed and encouraged to engage in outside remunerative practice to a degree which augments their usefulness as teachers and educational administrators.

Types of Educational Programs Needed. Regarding the types of educational programs needed, the Board's findings were as given below:

1 Secondary-school graduates who are qualified to profit by an extended fundamental preparation and who purpose definitely to enter the field of engineering are best served in general by a distinctive program of college work which includes as integral features: (*a*) an introduction to mathematics and the physical sciences planned with reference to engineering needs and taught in connection with concrete examples; (*b*) an introduction to the forms of language, verbal, graphic, and symbolic, used in the realm of engineering; (*c*) an introduction to the social sciences, particularly economics; (*d*) appropriate elements of culture; and (*e*) an effective tryout of engineering aptitude and interest.

2 Secondary-school graduates desiring specialized technical training rather than an extended fundamental grounding, are best served, in general, by a course in a technical institute of non-collegiate type or in a junior college organized on similar lines.

3 In regions where technical institutes do not exist and where junior colleges are not equipped to meet the need, it may be the duty of engineering colleges to provide intermediate technical training.

4 Irrespective of the length of the program, the distinctive training for administrative activities which is included in engineering curricula should be (*a*) complementary and not alternative to an extended grounding in science and engineering principles, and (*b*) an option which follows rather than one which parallels the introductory engineering program.

5 The coöperative type of program has given indications of unique merit as a means of meeting the need of men for training for line duties which ordinarily require an extended practical training as well as a sound educational grounding.

Present Facilities and Standards. Regarding present facilities and standards, the Board finds that:

1 The present group of colleges offering degrees in engineering is adequate numerically and sufficiently well distributed to meet present requirements for the recruitment of engineering services of professional grade.

2 Present facilities for the non-collegiate type of technical education are wholly inadequate.

3 The educational standards of the present group of engineering colleges compare favorably with those of all other equally comprehensive groups of undergraduate colleges.

4 A curriculum organized on the coöperative plan, so as to combine high-grade educational facilities with industrial experience, is an acceptable alternate to the usual college program.

5 Institutions having deficiencies in any of the above-named particulars should consider the alternative of up-grading their standards or of accepting a less ambitious status.

6 Further multiplication of engineering colleges should be discouraged for the present, unless the accessions to the group are of exceptional strength.

7 The influence at the command of the engineering colleges and the professional societies of engineers should be employed to direct new entrants to the realm of technological education into now inadequately filled fields of the technical institutes and the vocational schools.

A.A.A.S. Holds Annual Meeting in Philadelphia

An Interesting Feature of the Recent Gathering of Scientists and Engineers Was a Symposium Upon the Contributions Made by the Fundamental Sciences to the Advancement of Engineering and Industry

THE Annual Meeting of the American Association for the Advancement of Science was held in Philadelphia, December 27, 1926 to January 1, 1927. One of the interesting features of the program of Section M (Engineering) was the symposium on the contributions that have been made by the fundamental sciences to the advancement of engineering and industry. The subjects covered in this symposium, and the authors, were: Astronomy, by Frank Schlesinger, director of the Yale University Observatory; Mathematics, by Gilbert Ames Bliss, of the University of Chicago; Biology, by Henry B. Ward, of the University of Illinois; Chemistry, by Charles H. Herty, of the Chemical Foundation; Economics, by Joseph H. Willits, of the University of Pennsylvania; Geology, by Heinrich Ries, of Cornell; Medical Science, by Randle C. Rosenberger, of Jefferson Medical College, and Psychology, by J. McK. Cattell, editor of *Science*.

Celestial Bodies the Clocks and Calendars of the Ancients

Dr. Schlesinger point out that astronomy was one of the earliest sciences cultivated and that without its aid men of thousands of years ago would have been seriously handicapped in their struggles with nature and with rival nations. It is a peculiar fact that in those early days every man knew the stars and their habits intimately, but today because of the growth of cities few have more than a very slight acquaintance with the skies.

The celestial bodies were the clocks and the calendars by which ancient races regulated their lives. They also knew of the relation between moon and tides. From this beginning grew the science of navigation, which has changed the whole fabric of the world's industrial organization. The progress of science has taken away from astronomy almost all of its ancient opportunities to serve industries. The development of clocks and almanacs has removed astronomy from direct contact with the public, and recent developments in radio will soon render astronomical observations and calculations unnecessary on shipboard.

At the same time science has provided astronomers with equipment of tremendous power and minute accuracy. By these their contributions to pure science have been multiplied, and they have been of great help to chemists and physicists in spectrum-analysis problems by rendering the heavens useful as a vast laboratory.

The Calculus and Practical Engineering

Dr. Bliss handled the subject of mathematics in a manner which makes the paper of interest to any one. He said that the term "pure mathematics" is a misnomer, in that nearly all such work has or will eventually find practical application. He distinguished between commonplace mathematics, comprising algebraic or geometric principles, and the calculus, which is separated from the elemental by definite intellectual and physiological barriers.

After telling something of the growth and importance of simple mathematics, he turned to the consideration of the nature of the calculus and its effect upon practical engineering. He showed how such tables as those used by navigators, while comparatively simple in themselves, were based upon extensive computations in the calculus. The same was true of tables used in artillery firing. In commenting upon the relations between mathematics and the engineer, Dr. Bliss stated this principle: "Common sense should be scrupulously avoided in places where common sense does not apply." He explained this by mentioning that no amount of common sense unaided could predict the motions of the heavenly bodies or construct a range table.

The Engineer's Debt to Biology

Dr. Ward began his paper on biology by the statement that a study of this science on the part of primitive man gave the impulse for the construction of such early machines as traps, pitfalls, etc. The term "horsepower" was mentioned as one in the language of engineering which might be said to be of biological origin. Of the instruments which engineers owed to biology, the microscope was the most important.

Dr. Ward spoke of several important industries in which biological studies had led to marked progress. Among these studies were those in fermentation, in the habits of the shipworm which destroys marine woodwork, and the silkworm which spins the raw-silk fibers. A peculiar example cited was the great effect upon flood prevention of biologists' studies upon the root systems of plants and their relation to soil, and upon the types and habits of burrowing animals. He closed with a description of the great parts played by preventive medicine based upon biology in the successful carrying out of great engineering projects which would once have been hampered or rendered impossible because of hookworm, malaria, yellow fever, and the plague.

New Chemical Industries Resulting from Pure-Science Research

Dr. Herty opened his paper on chemistry with a plea for engineers to coöperate with Secretary Hoover in getting industries to support the prosecution of research in pure science. Only in this way, he said, could industry hope to continually progress. He gave credit to the group of popular writers who have within recent years developed among the chemists, for advancing this cause very materially.

He showed how many chemical industries which originally developed through pure empiricism have been revolutionized by the application of principles derived from pure science. At the same time entirely new industries have been brought into being by the same means.

Illustrations of this have been seen in the development of by-product industries under the supervision of chemical engineers. Not only have materials which were formerly waste been put to profitable uses, but in some cases these former waste products have acquired a value far in excess of what was originally the main product. There was a time, for instance, when the production of kerosene was attended by a vexing problem of disposing of a waste liquid called gasoline.

Dr. Herty contrasted the accidental discovery of aniline mauve by Perkin in 1856 with the orderly research into aniline products following the vision by Kekulé in 1865 of the structure of the molecule of benzene. Upon his theory the great coal-tar industries have grown up and are producing quantities of synthetic dyes, medicinal products, aromatics, flavors, photographic chemicals, high explosives, etc.

Contributions of Economics to Business

Dr. Willits began his paper upon economics by calling attention to the fact that industrial managers deal not only with problems whose roots lie in such fields as chemistry, physics, and mathematics, but also with those whose roots lie wholly or in part in the field of economics.

He cited the importance of the rules of navigation as evolved by scientists in the operation of great steamships, showing that such rules had been evolved before the advent of huge ships. In the business world, on the other hand, the industrial "machine" had grown up too suddenly to allow a corresponding development of the laws of navigation in the business world. In other words, knowledge of where to steer had not kept pace with knowledge of how to build the machine. We were still midway between the stage of high-grade empirical seamanship and a science of navigation in industrial management.

Dr. Willits classified the major contributions of economics to business as: The definition and scientific study of phenomena and

problems in economic and business life; the training of research workers for industry; education for administration in industry and business; and the education of public opinion and the elevation of the standard of business ethics. The body of the paper was devoted to the simplification of these topics.

Geology's Services in Engineering

Dr. Ries had no difficulty in proving the distinct and important connection between the science of geology and engineering. In the first place he identified geology as a comparatively new science. He placed its origin in the vague speculations of the cosmogonists not over two centuries ago. It was only organized during the last century and had assumed wide practical application only during the last thirty or forty years.

Dr. Ries classed the main problems in which applied geology is important as: water supply; railroad construction; military science; mapping; metal mining; coal; oil; agriculture; chemical industry; electrical industry; and what he called "political geology."

After amplifying upon each of these topics, he summed up by stating that geology is of service to man in two general ways. The first is the exploring and evaluating of mineral resources on which industry and civilization are based. The second is the application of geologic principles to various lines of human activity such as engineering, agriculture, chemistry, etc.

Health Activities of Engineers

Dr. Rosenberger mentioned some of the health activities of engineers as the selection and maintaining of safe water supplies, the disposal of sewage and other such wastes, the removal of irritating and poisonous dust and fumes, the development of safety devices in factories, and the perfection of food-handling machinery.

In the matter of water supply he mentioned the selection at the source and the storage and convenience as all requiring close guarding against pollution. In case pollution was unavoidable there entered the problem of chemical purification. Sewage disposal and other waste disposal brought up the matter of soil pollution, which in turn brought in the question of hook-worm disease. Another engineering problem with medical aspects was that of mosquito eradication.

The work of engineers had again touched the realm of the physician in the development of goggles, masks, and helmets for industrial use. Also the introduction of sun-lighted factories and periodic physical examinations of workers were important. Engineers could also coöperate in the treatment of tuberculosis by providing sanitariums for the segregation of sufferers, and by having children of ignorant or poverty-stricken, diseased parents properly cared for.

The production and distribution of milk was another health problem in which the engineer participated. Model dairies, pasteurizing plants, etc., showed conclusively the important results of medical coöperation with engineers.

Psychology Closely Related to Engineering

Dr. Cattell said that psychology, in the form of applied psychology and psychological engineering, was a science whose great application to engineering ends lay mainly in the future. Nevertheless, when looked upon as the science of how men think and act, psychology actually was the principle concern of primitive man and even of lower animals.

He explained the late development of this as a science by the fact that while matter was plastic to experiment and measurement, minds and behavior eluded experimental and quantitative methods. Engineering, he said, had a certain analogy to psychology in its early use and late development into a science. Though engineering works of great magnitude were constructed by the Egyptians and the Romans, the first schools of engineering were established only about a hundred years ago.

He quoted the following from a painting in the Engineering Societies Library in New York. "Engineering—the art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race." In view of this definition the relations between engineering and psychology were close, as the selection, training, and directing of men were problems of applied psychology. It was also for psychology to determine what did in fact benefit the human race. It was along this line of thought that the body of the paper was carried out and a convincing case made for the industrial psychology of the future.

Other Papers of Interest to Engineers

Among other papers of interest to mechanical engineers were: Dynamical Effect of a Moving Load on the Deflection of Bridges, by S. Timoshenko; The Representation of Low-Frequency Surges in Large Interconnected Electrical Systems by Means of Equivalent Networks, by Vladimir Karapetoff; The Relationship Between Science and the Study and Testing of Engineering Standards, by W. H. Fulweiler; Contributions of Science to the Lighting Art, by M. Luckiesh, past-president of the Illuminating Engineering Society; and the Stimulation of Research in Pure Science that Has Resulted from the Needs of Engineers and of Industry, by Dr. W. R. Whitney, director of the Research Laboratory of the General Electric Company, Schenectady, N. Y. Dr. Whitney's paper is published elsewhere in this issue of Mechanical Engineering.

At this meeting Dr. Arthur N. Talbot, of the University of Illinois, past-president of the American Society of Civil Engineers, was elected a vice-president of the A.A.A.S. and was also appointed chairman of the Section M Committee, succeeding as chairman Dr. Charles Russ Richards, president of Lehigh University. John Lyle Harrington of Kansas City, past-president of The American Society of Mechanical Engineers, was appointed to this committee, succeeding Allen B. McDaniel of Washington, D. C. Two other active members of the A.S.M.E. who continue upon the committee are Dr. Ira N. Hollis and Dr. Alexander C. Humphreys.

The Larger View of Industrial Progress

By CHARLES M. SCHAWB, PRESIDENT, A.S.M.E.

AT NO TIME in history have the people of an entire nation enjoyed the prosperity prevalent in the United States today. At no time have people dreamed of the universal use of luxuries which we accept as our birthright. Our material prosperity is astounding—so remarkable, in fact, that business men are coming from all parts of the world to study our methods.

It is my hope that our spiritual and cultural prosperity will now show similar development. We have conquered poverty. Let us conquer disease. We have abolished illiteracy. Let us develop finer methods of education. We have saved time and increased production by making machines do our work. Let us make worth while our additional leisure.

We still have many problems before us. Our very prosperity makes foreign manufacturers cast envious eyes at our markets. To maintain our markets and our present high wages with reasonable profits for manufacturers, we must realize efficiency and economies on a progressive scale, not merely in production, but in marketing methods as well.

Both in industry and in agriculture there must be coöperation among the factors involved to an extent never before considered necessary or even desirable. Farming must be conceived on a more scientific basis. There must be greater integration of agricultural producing units. We must apply to our fields the methods of large-scale production that have been found successful in our factories. Waste in marketing must be minimized on the farm as well as in industry.

These things can and will be done through the coöperation of heads of industries, farmers, bankers, Wall Street men and ranchers. We have the greatest country in the world, and with intelligent effort, a feeling of humility, and faith in one another, nothing is beyond our power of achievement.—Text of an interview appearing in *Machinery*, January, 1927, p. 339.

Book Reviews and Library Notes

THE Library is a coöperative activity of the A.S.C.E., the A.I.M.E., the A.S.M.E. and the A.I.E.E. It is administered by the United Engineering Society as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West 39th St., New York, N. Y. In order to place its resources at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references on engineering subjects, copies of translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

A New Treatise on Steam Turbines

STEAM TURBINES. By Professor G. Belluzzo. Translated by Engr. Captain A. G. Bremner, O.B.E., R.N. Charles Griffin & Co., Ltd., London, 1926. Paper 6 × 9 in., 732 pp., 750 illus., diagrams and tables. 42 s.

RELATIVELY few comprehensive treatises on steam turbines have been printed in English. Hence a new book of 42 chapters and 746 pages cannot fail to arouse interest.

The original text was written in Italian by Professor Belluzzo of the Milan Polytechnic, who has designed many turbines and has directed extensive research on the action of steam in turbine parts.

A striking feature of the book is the excellence of the translation. The phraseology is clear and definite, and the typographical errors are few.

Like most continental writers, Professor Belluzzo adopts the mathematical method to present his material and makes little attempt to discuss the physical nature of the particular phenomena under consideration. Americans prefer to have a mental picture of the nature of the process, and hence our books on this subject are more descriptive in nature and employ more empirical formulas than the one under review.

In the opening chapters, the properties of steam are based on Continental researchs and no mention is made of A.S.M.E. work. Elementary thermodynamics, cycles, and the theory of the flow of steam are discussed, and the usual formulas are derived. The theory of shock is presented from a dynamical point of view. The author endeavors to show that compression results in the jet from impact on a surface.

The theory of flow of steam in curved passages will be new to many readers. The author holds that a jet of steam when deflected in a curved passage is subjected to compression by the action of the forces that result from its deflection around the curved surface. This compression leads to energy losses, and this accounts for the losses that occur in crossing blade or curved-orifice surfaces. This analysis leads to the conclusion that wide blades with large radii of curvature are needed in the moving rows of impulse turbines when high steam velocities occur, and also that large blade angles, both inlet and outlet, are conducive to high efficiency. His conclusion that these angles should be equal for highest efficiency will be questioned, for it is now generally understood that the efficiency of an impulse wheel with properly designed blading is increased when the size of the outlet angle is slightly decreased. The reaction turbine is analyzed in the same manner as the impulse.

The value of the coefficient for losses in crossing blades is derived by analyzing various European test data by the author's centrifugal-force method. He concludes that these losses increase with increasing velocity, which seems a reasonable conclusion. There may be some question as to the accuracy of his values in view of the later research work on blades in American laboratories. His treatment of blade and nozzle design is based on these ideas that he developed.

Considerable space is devoted to a discussion of various types of turbines. Attention is called to the possibilities of a single reaction stage to drive small high-frequency alternators.

The designs of turbines follow standard lines with the usual methods of computing mechanical and leakage losses. This section does not seem to be as complete as the corresponding portion of Goudie's latest edition of his book on Steam Turbines. Chapters are devoted to steam consumption, governing, and the mechanical design of all turbine parts. The author does not discuss blade or disk vibration, which have received so much attention during the last few years, nor does he consider recent developments in dynamic balancing.

The last part of the book presents constructional details and standard European designs of land and marine turbines and reduction gears. A final chapter discusses the turbine locomotive.

The author says very little about regenerative or reheating cycles and the influence of these on steam-turbine calculation and design. It seems evident from reading the book that the original Italian text must have been prepared about four years ago. This undoubtedly accounts for the omissions noted above, as many of these developments are of comparatively recent date. All books dealing with as rapidly developing an art as steam-turbine design must be subject to the criticism that between the time of writing and of publication many of the illustrations and methods presented become out of date.

The designer of turbines will not find much new material in this book. A student of turbine theory will find many portions that should prove of interest. It will prove a vauable contribution to our literature by providing some new viewpoints on steam-turbine theory.

A. G. CHRISTIE.[1]

Data on Heating and Ventilation

THE HEATING AND VENTILATING ENGINEERS' GUIDE. The American Society of Heating and Ventilating Engineers, New York, 1926–1927. Fifth edition, 6 × 9 in., 580 pp. $3.

THE Heating and Ventilating Engineers' Guide contains design and specification data (cross-indexed in a comprehensive manner) useful in the planning and construction of modern heating and ventilating installations. It was prepared and published by The American Society of Heating and Ventilating Engineers, with the coöperation of a large and important committee of practicing heating and ventilating engineers: the material being taken from society transactions, from investigations of the society's research laboratory, and from the best practice of society-member engineers.

In addition to engineering and practical data, the Guide contains a very useful and valuable advertising section which is carefully edited and controlled and in which the manufacturer gives information in reference to his product. The advertising (which is in condensed form) serves the contractor, engineer, and architect as a ready reference in heating and ventilating matters in a manner somewhat similar to the more general Sweet Index.

Practically every phase of the work of the heating engineer is dealt with in considerable detail. In most cases the material in the more basic subjects has been prepared by engineers who are authorities in their particular fields.

Any one interested in the design, operation, specification, or purchase of heating and ventilating equipment will find the book

[1] Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

of value, and all technical and public libraries should contain a copy.

As in the case of most treatises, some subjects are more completely covered than others, and there are some cases where special data now available could with advantage be added.

The Guide is published yearly in revised and amplified form, thus keeping abreast of best practices.

The present Guide is a high-class publication and may be confidently recommended to every one interested in the art of heating and ventilation.

FRANK TOMES CHAPMAN.[2]

Books Received in the Library

GRAPHIC CHARTS IN BUSINESS. By Allan C. Haskell. Second edition. Codex Book Co., New York, 1926. Cloth, 6 × 8 in., 413 pp., diagrams, charts, $4.

A practical book that omits mathematical discussion and goes directly to the question of the ways in which the business man may use graphic charts. The various types of charts are described, and the things that each will and will not show are explained. Definite instructions for the construction of each type are given. The use of charts in the various departments of a business are set forth and illustrated by reproductions of many charts.

LABORATORY MANUAL OF TESTING MATERIALS. By William K. Hatt and H. H. Scofield. Third edition. McGraw-Hill Book Co., New York, 1926. Cloth, 5 × 8 in., 182 pp., tables, $2.

This manual, which is based on long experience in testing and in teaching, attempts to show the student the technological purpose of various tests, train him in the technique of testing and give him some knowledge of materials. It also endeavors to develop his critical faculties. The third edition reflects recent changes in standard methods and shifts the emphasis upon the several experiments. Some changes of omission and addition have been made.

MACHINE DESIGN. By Louis J. Bradford and Paul B. Eaton. John Wiley & Sons, New York, 1926. Cloth, 6 × 9 in., 249 pp., illus., diagrams, tables, $2.75.

An unusually brief textbook, intended for use in courses where time is limited. The objects sought are to ground the student in the fundamental facts and processes; to train him to analyze problems, recognize the principles involved and apply sound methods of solution; and give him a general knowledge of good practice. The book is designed to be covered in about twenty-five lessons and is intended to teach the use of data rather than to be a source of data.

MAGNETISM AND ATOMIC STRUCTURE. By Edmund C. Stoner. E. P. Dutton & Co., New York, 1926. Cloth, 6 × 9 in., 371 pp., diagrams, $5.

Intended as a supplement to ordinary works on magnetism, this book gives an account of magnetic phenomena, and of the attempts made to interpret them in terms of the quantum theory. The treatment is semi-historical. The author has attempted to make the book complete within the selected range. His method is to give reasonably complete outlines of representative researches, and to base discussions upon these.

MATHEMATICAL AND PHYSICAL PAPERS, 1903–1913. By Benjamin Osgood Peirce. Harvard University Press, Cambridge, 1926. Cloth, 6 × 9 in., 444 pp., illus., portraits, diagrams, tables, $5.

The twenty-one papers here assembled appeared originally in the Proceedings of the American Academy of Arts and Sciences or in the American Journal of Science. They include practically all those published by Professor Peirce during the last ten years of his life, and this republication will be welcome to many scientists. A bibliography of Professor Peirce's writings is included.

METALLURGY OF THE COMMON METALS. By Leonard S. Austin. Sixth edition. John Wiley & Sons, New York, 1926. Cloth, 6 × 9 in., 658 pp., illus., diagrams, $7.

Austin's metallurgy is intended especially for the student of mining and aims to give him a general outline of the metallurgy of the metals with which he will practice, as a preliminary to the detailed study of individual metals. The book opens with a section on the treatment of ores, fuels, refractories, sampling, crushing, furnaces, roasting, and concentration. The concentration, reduction, and refining of the individual metals are then considered. Special attention is given to underlying principles, but details of processes and the design and operation of plants are also considered.

NEW HEAT THEOREM. By W. Nernst. E. P. Dutton & Co., New York, 1926. Cloth, 6 × 9 in., 281 pp., $4.

Nernst's heat theorem asserts that the temperature coefficients of the free and total energy in any system decrease to indefinitely small values as absolute zero of temperature is approached. This hypothesis is offered as a third law of thermodynamics and, while it cannot be directly verified, it has been found to agree satisfactorily with experiment. It enables the maximum work of a system to be calculated from heat measurements alone.

In the present book Dr. Nernst gives a historical account of the theorem and describes the researches undertaken by him and his fellow-workers to test its validity and to discover its applications.

NIETEN UND SCHWEISSEN DER DAMPFKESSEL. By E. Höhn. Julius Springer, Berlin, 1925. Paper, 6 × 9 in., 146 pp., diagrams, tables, 8 r.m.

This brochure gives a detailed discussion of the extensive tests of riveted and welded joints carried out at the instigation of the Swiss Association of Boiler Owners during 1924 and 1925. The conditions of the tests, the results, and the conclusions derived are set forth.

NOTES ON THE INDUCTION MOTOR. By H. E. Dance. Oxford University Press, London and New York, 1926. Cloth, 5×8 in., 152 pp., diagrams, $2.

This book is intended for students of engineering who do not wish to study the induction motor from the viewpoint of the designer, yet who wish a thorough working knowledge of it. It aims to present compactly a complete approximate theory of the motor, with notes on starting, speed control, and power factor. Those details that are of interest to students of design alone have been omitted.

PERSONNEL ADMINISTRATION, ITS PRINCIPLES AND PRACTICE. By Ordway Tead and Henry C. Metcalf. Second edition. McGraw-Hill Book Co., New York, 1926. Cloth, 6 × 9 in., 543 pp., $5.

Aims to set forth the principles and the best prevailing practice in the field of the administration of human relations in industry. This field includes the various efforts—health and safety, training, personnel research, services and joint relations—that are usually grouped as personnel management, and also a consideration of associations of employers and their dealings with national organizations of workmen.

The new edition has been revised throughout, to meet the advances that have occurred during the past six years.

POWER PLANT TESTING. By James Ambrose Moyer. Third edition, enlarged. McGraw-Hill Book Co., New York, 1926. Cloth, 6 × 9 in., 609 pp., illus., diagrams, tables, $5.

Describes in some detail generally approved methods of testing these machines, and also describes the apparatus used and the calibrations required for accurate testing. While intended primarily for students in laboratory courses, the book also aims to give engineers who are not thoroughly familiar with up-to-date methods a survey of those now in use.

The new edition conforms to the latest codes adopted by the various societies and committees, and has been revised throughout.

WÄRMEWIRTSCHAFT IM EISENHÜTTENWESEN. By Max Schlipköter. Theodor Steinkopff, Dresden and Leipzig, 1926. (Wärmelehre und Wärmewirtschaft. . . . bd. 3.) Paper, 6 × 9 in., 119 pp., illus., diagrams, tables, 7 r.m.

This small book aims to give the manufacturer of iron and steel a concise, specific account of the ways in which modern findings in heat economy may be applied to his business. The latest theories of heat and the devices and methods that have survived practical tests are described. The book covers heat economy at the blast furnace and in the steel-works, the rolling mill, and the foundry, the production of power, and the heating of the plant.

[2] Consulting Sales Engineer, Montclair, N. J. Mem. A.S.M.E.